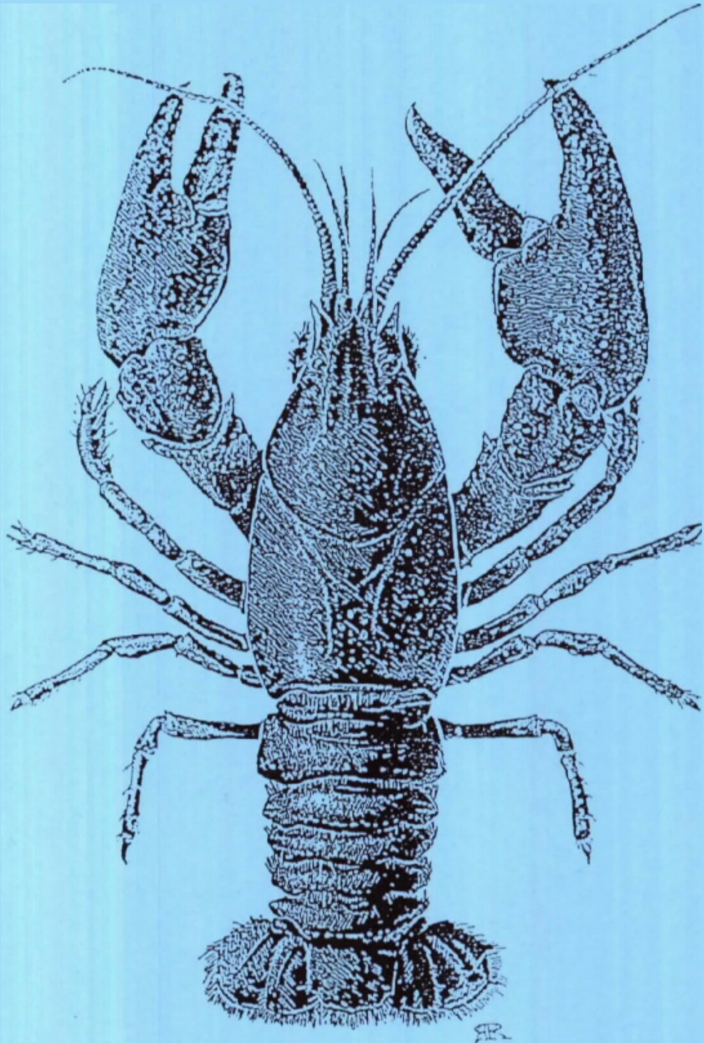
U.S. Fish & Wildlife Service

Recovery Plan for the Shasta Crayfish

(Pacifastacus fortis)



RECOVERY PLAN

for the

SHASTA CRAYFISH
(*Pacifastacus fortis*)

Published by

Region 1
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The *Pacifastacus fortis* illustration by Randy Schmieder used on the cover was reprinted from *Life on the Edge*, courtesy of Biosystems Books and Randy Schmieder (© R. Randy Schmieder). The U. S. Fish and Wildlife Service would like to thank the Smithsonian Institution for the use of the illustration of Shasta and signal crayfish used in Appendix A (Hobbs 1989).

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EXECUTIVE SUMMARY

Current Status: The Shasta crayfish (*Pacifastacus fortis*) is federally and State listed as endangered. Its distribution is limited to the midsections of the Pit River drainage, primarily the Fall River and Hat Creek subdrainages in Shasta County, California. This species' distribution is tied to the distribution of lava cobbles and boulders originating in the volcanic geology of the Modoc Plateau. Overall, Shasta crayfish populations have low abundance and fragmented distribution with migration and genetic exchange between populations limited by hydroelectric development, natural barriers, and habitat loss. The limits of its geographic range, however, appear to have changed little over time. Currently, there are seven populations of Shasta crayfish ranging in size from approximately fewer than 50 to 5,000.

Habitat Requirements and Limiting Factors: Shasta crayfish primarily live in cool, clear, spring-fed headwaters that are characterized by clean volcanic cobbles and boulders on top of gravel or sand. The volcanic cobble and boulders are essential habitat components because they provide protective cover for the crayfish. The main threats to Shasta crayfish include the introduction and expansion of nonnative species of and fishes and disturbances related to land use practices. Signal crayfish, which are rapidly expanding their abundance and range, must immediately be excluded from the major subpopulations of Shasta crayfish, and eradicated and controlled elsewhere, to prevent the extinction of Shasta crayfish.

Objective: The primary objective of this plan is to stabilize and protect existing populations so that Shasta crayfish may be reclassified as a threatened species and ultimately delisted.

Criteria for Downlisting (status changes from endangered to threatened):

1. The 20 major subpopulations within 5 Shasta crayfish populations that are currently free of nonnative crayfish species are protected to ensure they remain isolated from nonnative crayfish species, and these subpopulations are stable (i.e., self-sustaining and comprising representatives of all age classes).

2. The Crystal Lake and Sucker Springs Creek subpopulations, which have been invaded by signal crayfish, are protected and stable due to elimination, reduction, or management of signal crayfish.

3. Over a 5-year period, population sizes remain constant at Upper Fall River, Spring Creek, and Rising River, and population sizes increase at Lava Creek, upper Tule River, Crystal Lake, and Sucker Springs.

4. Signal crayfish are eradicated in lower Lava Creek so that Shasta crayfish are free of signal crayfish throughout the entire Lava Creek subdrainage.

5. The major subpopulations in each of the seven Shasta crayfish populations are protected from disturbances related to land use practices.

Criteria for Recovery and Delisting (species is no longer federally threatened or endangered):

1. Nonnative crayfish species, in particular signal crayfish, have been eliminated, reduced, or managed in all Shasta crayfish subpopulations, so that they no longer threaten the continued existence of Shasta crayfish at these sites.

2. All Shasta crayfish subpopulations are stable with population sizes that are increasing over a 5-year period.

Actions Needed:

1. Protect Shasta crayfish populations by eradicating or preventing invasions by nonnative crayfish, restoring habitat, and eliminating impacts from land management practices.
2. Determine the status, distribution, and relative abundance of Shasta crayfish in the mainstem of the Pit River.
3. Conduct research on the ecology, behavior, and pathology of Shasta crayfish.
4. Monitor and assess Shasta crayfish populations and determine population targets for a sustainable and well-distributed population.
5. Develop effective watershed and ecosystem management plans for all drainages supporting Shasta crayfish populations.
6. Provide public education on Shasta crayfish.

Costs: approximately $4,500,000

Date of Delisting: 2012

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I. INTRODUCTION

A. Brief Overview

The continued existence of the Shasta crayfish (*Pacifastacus fortis*), the only surviving species of crayfish native (endemic) to California, is at risk. Originally designated as a rare species under California law in 1980, the Shasta crayfish was listed as an endangered species by the State in 1988. The Shasta crayfish was federally listed as an endangered species on September 30, 1988 (U.S. Fish and Wildlife Service 1988). No critical habitat has been designated for this species.

The limited distribution and abundance of Shasta crayfish, coupled with an apparent decline in the species, led to its endangered status. Its distribution is limited to the midsections of the Pit River drainage, primarily the Fall River and Hat Creek subdrainages (Figure 1). The greatest densities of Shasta crayfish are found in the pristine headwater springs of the Fall River. A few of these springs support locally abundant isolated populations. Other areas, which have generally been considered marginal habitat, support a sparsely distributed, low abundance of crayfish. Overall, Shasta crayfish have a low abundance and fragmented distribution with migration and genetic exchange between populations limited by hydroelectric development, natural barriers, and loss of habitat. No single event is responsible for the species' decline, but numerous natural and human disturbances over time have collectively resulted in the reduced abundance and fragmented distribution of the Shasta crayfish.

Of the three species of crayfish endemic to California, only the Shasta crayfish (formerly called the placid crayfish) remains. The sooty crayfish (*Pacifastacus nigrescens*), which is the species considered to be the most closely related to Shasta crayfish, has not been collected since the mid-1800s. Once a common inhabitant of creeks in the vicinity of San Francisco, the sooty crayfish is now considered extinct due to overharvesting, urbanization, and the introduction of the

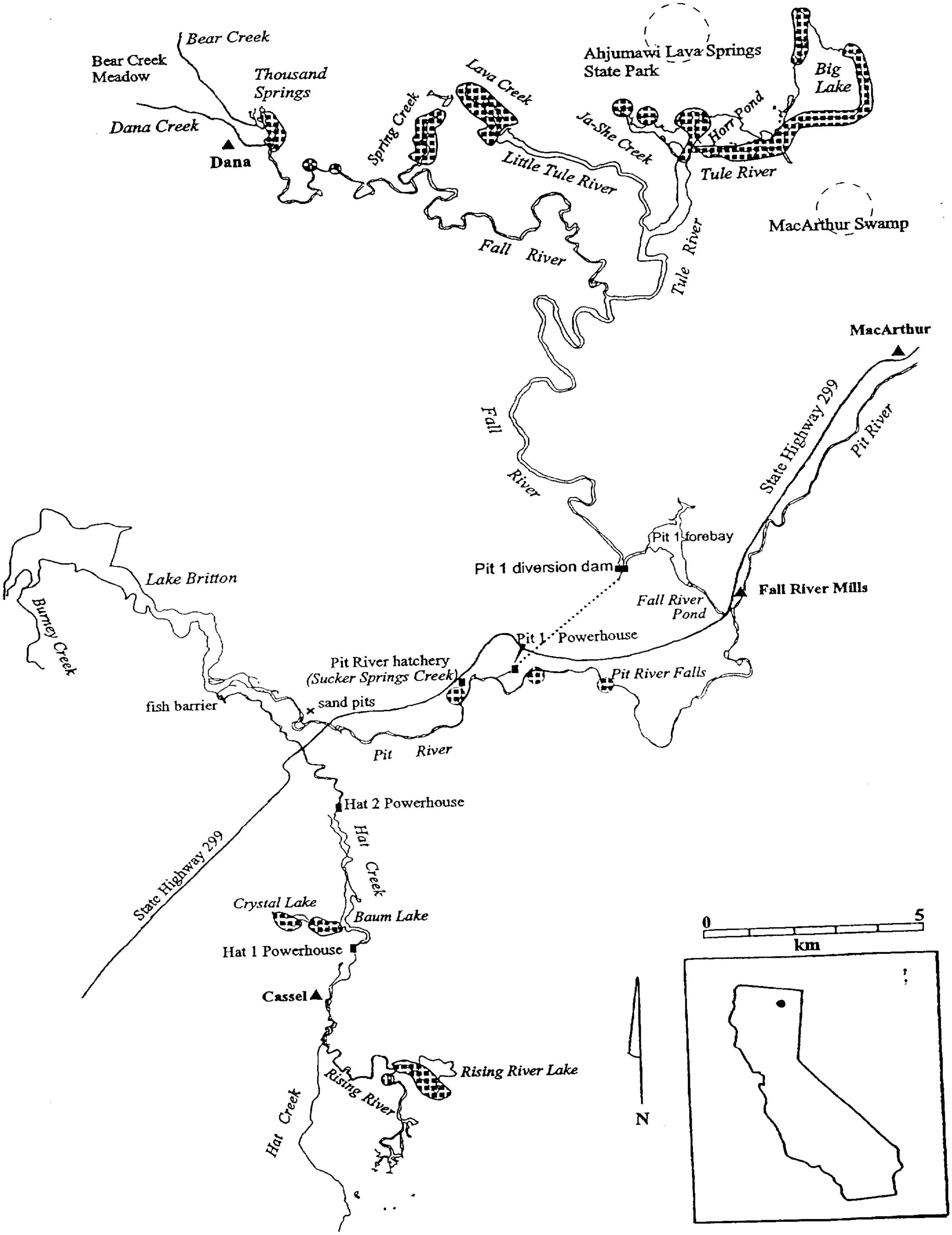

Figure 1. Distribution of all known locations of Shasta crayfish in Shasta County, California.

nonnative signal crayfish (*Pacifastacus leniusculus leniusculus*) to the San Francisco Bay area in the late 1800s (Reigel 1959, Hobbs 1974, 1989, Bouchard 1977a). Subspecies of *Pacifastacus leniusculus* have been widely introduced throughout the state and world, including the Klamath River drainage in northwestern California where one subspecies (*Pacifastacus leniusculus klamathensis)* is native. Because of overlapping ranges and interbreeding, the different subspecies of *Pacifastacus leniusculus* are generally no longer recognizable (Hobbs 1972); characteristics once useful in distinguishing the subspecies are now often found on the same individual.

Within the last two decades, the signal crayfish was also introduced into the native drainage of the Shasta crayfish in northeastern California. Many events or disturbances in the last century have changed the habitat so that it is now more suitable to a generalist such as the signal crayfish, which is a species that tolerates a broad range of conditions, than to a specialist such as the Shasta crayfish, which is a species that is adapted to a narrow range of conditions. The rapid expansion of signal crayfish and the apparent decline of Shasta crayfish in this area suggests that signal crayfish may replace Shasta crayfish as the signal crayfish once probably replaced the sooty crayfish in the San Francisco Bay area.

B. Taxonomy

Shasta crayfish were first collected by Rutter and Chamberlain in 1898 in the Fall River at Fall River Mills and Hat Creek near Cassel during a United States Fish Commission study (Rutter 1903, 1908). Fall River Mills is the type locality, the place where the specimen(s) used to describe the species' distinguishing characteristics was collected. Faxon (1914), using Rutter's 1898 collections, described Shasta crayfish as *Astacus nigrescens fortis*, because he believed it was a subspecies of the San Francisco Bay area sooty crayfish. Bott (1950, cited in Eng and Daniels 1982) separated the North American members of this genus into the genus *Pacifastacus* and retained the generic name *Astacus* for some of the Eurasian members of the genus. Hobbs assigned full species status to the Shasta crayfish, *Pacifastacus fortis*, in 1972. The Shasta crayfish remained in the family Astacidae when Hobbs created the family Cambaridae in 1972 for all crayfish species that have two morphological forms for the male. All Cambarids are native to areas east of the Continental Divide. Bouchard (1978) placed Shasta crayfish in the subgenus *Hobbsastacus* because the rostrum, the area between the eyes in the most anterior portion of the carapace (the shell covering the head and midregion over the walking legs), has multiple pairs of marginal spines (Figure 2). The spiny rostrum of the Shasta crayfish is similar to the rostrums of four other members of the genus *Pacifastacus* that are also placed in the subgenus *Hobbsastacus*: *P. chenoderma* (fossil), *P. connectens*, *P. gambelii*, and *P. nigrescens*.

C. Species Description

Shasta crayfish are medium-sized; the total carapace length (TCL) (see Figure 2) of a typical adult is 27–50 millimeters (1.06–1.97 inches). The most common coloration pattern for Shasta crayfish is a dark mocha brown on the back and a bright orange red on the underside, especially on the pincher-like claws (chelae). An occasional individual has a blue-green to bright blue dorsal (back) surface and a light salmon ventral (underside) surface.

Shasta crayfish have a toothed (denticulate) margin on the rostrum (Figure 2). In signal crayfish, the rostrum has three parts or protrusions (tripartite rostrum). The inside margin of the chelae of the Shasta crayfish is smooth, while the chelae of the signal crayfish is notched. Appendix A illustrates the physical characteristics that differentiate the signal crayfish from the Shasta crayfish. The absence of patches of bristles (setal patches) on their claws separate Shasta crayfish from

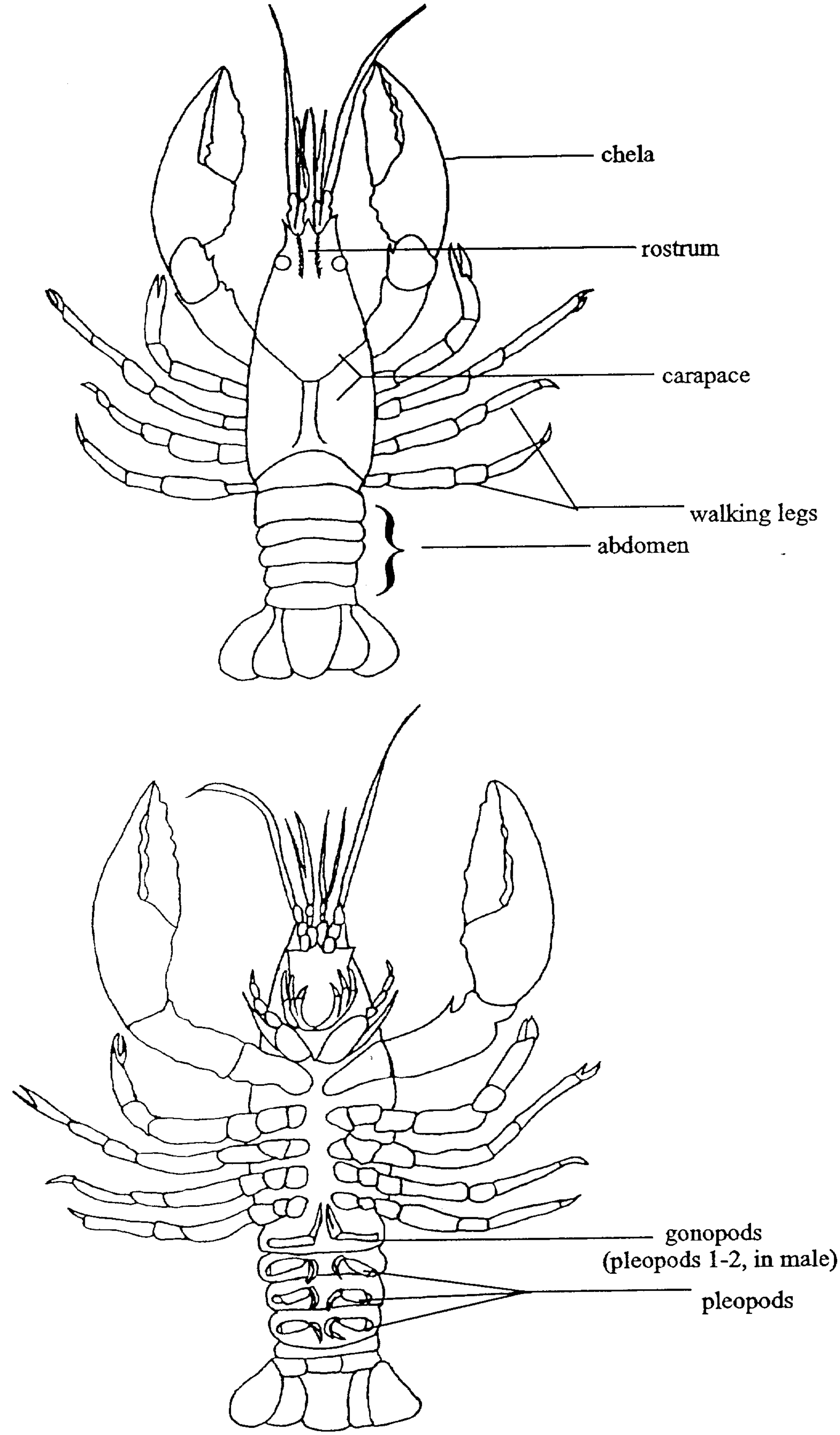

Figure 2. Illustration of a crayfish.

Pacifastacus connectens (native to Idaho, northern Nevada, northern Utah, and eastern Oregon) and *Pacifastacus gambelii* (a northern Rocky Mountains/Great Basin species). Shasta crayfish have shorter and thicker claws than the sooty crayfish, whose claws are long and narrow (Hobbs 1989).

Male and female Shasta crayfish differ physically (sexually dimorphism). The first two pairs of abdominal appendages (pleopods or swimmerets) are hardened and modified in males for sperm transfer to females. In addition, adult males have narrower abdomens and larger claws than females. Adult females have broader abdomens with lateral extensions of the exoskeleton on the abdomen (pleura); the first pair of abdominal appendages is absent in females.

D. Life History and Ecology

Most crayfish are more active at night. Shasta crayfish are especially nocturnal and remain hidden during the day. In general, Shasta crayfish come out from hiding only after dark to browse on the periphyton (i.e., the community of plants, animals, and associated detritus, or debris) that adhere to and form a surface coating on the abundant lava rocks. Shasta crayfish that are found in the open during daylight have generally either been disturbed from their refuge or appear ill (M. Ellis, personal observation [pers. observ.]).

Shasta crayfish are long-lived and slow-growing. Although age-class boundaries are often not very distinct, especially in older reproductive crayfish, the relative age of individual Shasta crayfish can be estimated from graphs based on data showing the relationship between age and size (size-frequency histograms). It takes 5 years for a Shasta crayfish to reach sexual maturity at 27 millimeters (1.06 inches) TCL. The largest Shasta crayfish found to date was a male, probably 10–15 years old, with a TCL of 58.7 millimeters (2.31 inches).

Mating occurs in October or November when the male deposits a capsule containing sperm (spermatophore) on the underside of the female near her genital opening at the base of the fourth pair of walking legs. Shortly afterwards, the female lays 10–70 eggs, which she fertilizes with sperm from the spermatophores and then attaches to the underside of her abdomen or tail. In the spring, the eggs hatch into immature larval forms, the first instars, that are attached to the underside of her abdomen by threads to the inner egg membrane. These molt into second instars, miniatures of the adult that clasp the female with their tiny claws. After a second molt, the third instars reach a total carapace length of 5–7 millimeters (0.20–0.27 inch) and gradually become free-living (Holdich and Reeve 1988).

Potential Food Resources. No research has determined the food preferences and nutritional requirements of Shasta crayfish, but there have been a number of observations and hypotheses based on anatomy and observation in the field and laboratory. The failure to capture this species by using baited traps (Eng and Daniels 1982) led to the premise that Shasta crayfish were either carnivores (meat eaters) or browsers (grazing on aquatic vegetation) rather than omnivorous scavengers (feeding on dead or decaying plants and animals) like signal crayfish, which are readily lured to baited traps. Bouchard (1977b) determined that the structure of the mouthparts makes Shasta crayfish more efficient at scraping foods such as periphyton than the signal crayfish, which has a more generalized incisor surface. Shasta crayfish have been observed in the laboratory and field feeding on the small blackish-green snail, *Fluminicola* spp. (M. Ellis, pers. observ.; T. Light 1990, unpublished [unpubl.] field notes). In the field, Shasta crayfish were observed apparently feeding on snails, a strand of dead aquatic vegetation that was probably a filamentous green algae (*Rhizoclonium*) (J. Clarke 1990 unpubl. field notes), and organic debris.

During night dives, researchers have observed Shasta crayfish on rocks with their mouthparts moving; this behavior suggests the crayfish are eating organisms attached to rocks (periphyton) and possibly snails; however, crayfish can also move their mouthparts as a sensory behavior when they are not feeding. Shasta crayfish have been observed moving their first walking legs (pereiopods) to their mouths or moving their claws to suggest feeding; although the crayfish were apparently grazing, no specific food items could be identified (M. Ellis, pers. observ.; Erman *et al.* 1993).

Other observations have been made under artificial or experimental settings that could affect crayfish behavior. Shasta crayfish kept in aquaria have fed on both freshwater limpets (*Lanx* spp.) and tubifex worms (Eng and Daniels 1982). During one series of experiments, Shasta crayfish were fed crayfish chow, meal worms, and brine shrimp (Mojica *et al.* 1993), all of which are not found in their native environment. It was unknown whether this diet met the species nutritional requirements. When almost all of these crayfish died, it was assumed to be a result of high water temperatures during the experiment. One Shasta crayfish was observed eating a dead juvenile rainbow trout during an enclosure experiment in Crystal Lake during the summer of 1993 (M. Ellis, pers. observ.). Shasta crayfish in the Pit 1 Laboratory have been observed eating numerous snails, particularly *Fluminicola* spp. and, to a lesser extent, *Juga* spp. (M. Ellis, pers. observ.)

The primary food of Shasta crayfish appears to be the periphyton and invertebrates that are abundant in their native environment. Other potential food resources include trout, sucker, and sculpin eggs, which are seasonally abundant. Although some of the items Shasta crayfish will consume are known, nothing is known about their actual nutritional requirements. Some understanding of the nutritional requirements of Shasta crayfish is necessary before initiating long-term captive breeding programs.

Potential Predators. Many native and introduced fish, amphibian, reptile, and mammal species in the midsections of the Pit River drainage are known to prey on crayfish (Table 1), although predation on Shasta crayfish has not been documented. Some species are occasional benthic feeders that would probably eat small crayfish, particularly young of the year (YOY), when encountered. Other potential predators include bullfrogs, turtles, garter snakes, mammals, and a variety of birds. Bullfrogs, which are not native west of the Rockies (Stebbins 1985), were introduced and are now common in Crystal Lake and Big Lake. Bullfrogs prey on crayfish (Tack 1941, Penn 1950). Although many turtles eat crayfish (Tack 1941, Lagler and Lagler 1944), no references to western pond turtle predation on crayfish were found. Garter snakes eat crayfish on occasion.

Two of the three native aquatic mammals, river otters and mink, are known to prey on crayfish. Observations of a pair of river otters feeding on signal crayfish in the Pit River indicate that they are extremely effective and efficient crayfish predators (M. Ellis, pers. observ.). Most of the river otter scat found in the area is composed solely of pieces of crayfish shell (M. Ellis, pers. observ.). Muskrats, which prey on crayfish, were introduced into the drainage in the early 1930's. Racoons are also known to eat crayfish. Beavers are herbivorous and unlikely to impact crayfish. The impact of these potential predators on Shasta crayfish is not known.

One of the largest great blue heron rookeries in California is located in Ahjumawi Lava Springs State Park (Figure 1) along Ja-She Creek. A smaller great blue heron rookery is found on an island in the Pit River downstream of the State Highway 299 Bridge. The impact of avian predators on Shasta crayfish is unknown.

Table 1. Animal and plant species associated with the Shasta crayfish in the Pit River and its subdrainages (Figures 1, 4, 5, and 8).

	Common Name	Scientific Name	Crayfish Predator	Comments
Fish[1]	Rainbow trout	*Oncorhynchus mykiss*	Yes	Spring areas; eggs are a potential food resource for Shasta crayfish
(Native)	Sacramento sucker	*Catostomus occidentalis*	Possible	Spring areas; eggs are a potential food resource for Shasta crayfish; possibly eat Shasta crayfish young-of-the-year (YOY)
	Pit-Klamath brook lamprey	*Lampetra lethophaga*	No	Spring areas; eggs are a potential food resource for Shasta crayfish
	Rough sculpin	*Cottus asperrimus*	Possible	Spring areas; found throughout Fall River drainage; low numbers in Pit River and lower Hat Creek (downstream from Rising River subdrainage); eggs are a potential food resource for Shasta crayfish; possibly eat Shasta crayfish YOY; State listed as threatened and Federal species of concern
	Bigeye marbled sculpin	*Cottus klamathensis macrops*	Possible	Spring areas; found throughout Fall River drainage; low numbers in Pit River and lower Hat Creek (downstream from Rising River subdrainage); eggs are a potential food resource for Shasta crayfish; possibly eat Shasta crayfish YOY; State species of special concern
	Sacramento squawfish	*Ptychocheilus grandis*	Yes	Lakes and rivers; spawn in spring areas

[1] Taub 1972; Rickett 1974; J. Cook, pers. comm. 1995; L. Eng, unpubl. data; California Department of Fish and Game, unpubl. records

Table 1. Animal and plant species associated with the Shasta crayfish in the Pit River and its subdrainages (Figures 1, 4, 5, and 8).

	Common Name	Scientific Name	Crayfish Predator	Comments
	Pit sculpin	*Cottus pitensis*	Possible	Only sculpin in Rising River subdrainage and upper Hat Creek; also native to lower Hat Creek, Sucker Springs Creek, and mainstem Pit River; not found in Fall River drainage, or Crystal Lake; eggs are a potential food resource for Shasta crayfish; possibly eat YOY crayfish
	Hardhead	*Mylopharadon conocephalus*	Possible	Native to midsections of Pit River drainage, but not generally found with Shasta crayfish; possibly eat YOY crayfish
	Tui chub	*Gila bicolor*	Possible	Native to midsections of Pit River drainage, but not generally found with Shasta crayfish; possibly eat YOY crayfish
	Tule perch	*Hysterocarpus traski*	Possible	Native to midsections of Pit River drainage, but not generally found with Shasta crayfish; possibly eat YOY crayfish
Fish[1]	Brown trout	*Salmo trutta*	Yes	Spring areas, especially in fall spawning season
(Introduced)	Brown bullhead	*Ameiurus nebulosus*	Yes	Crystal Lake
	Largemouth bass	*Micropterus salmoides*	Yes	Successful in using Shasta crayfish habitat, including some spring areas, especially in winter
	Green sunfish	*Lepomis cyanellus*	Yes	Not generally found with Shasta crayfish

[1] Taub 1972; Rickett 1974; J. Cook, pers. comm. 1995; L. Eng, unpubl. data; California Department of Fish and Game, unpubl. records

Table 1. Animal and plant species associated with the Shasta crayfish in the Pit River and its subdrainages (Figures 1, 4, 5, and 8).

	Common Name	Scientific Name	Crayfish Predator	Comments
	Bluegill	*Lepomis macrochirus*	Possible	Not generally found with Shasta crayfish; could possibly eat YOY crayfish
	Black crappie	*Pomoxis nigromaculatus*	Yes	Not generally found with Shasta crayfish
	Smallmouth bass	*Micropterus dolomieu*	Yes	Not generally found with Shasta crayfish
	Brook trout	*Salvelinus fontinalis*	Possible	Not generally found with Shasta crayfish; could possibly eat YOY crayfish
	Channel catfish	*Ictalurus punctatus*	Yes	Not generally found with Shasta crayfish
	White catfish	*Ameiurus catus*		Not generally found with Shasta crayfish
	Common carp	*Cyprinus carpio*	Possible	Not generally found with Shasta crayfish
	Golden shiner	*Notemigonus crysoleucas*	Possible	Not generally found with Shasta crayfish; large shiners could possibly eat YOY crayfish
	Black bullhead	*Ameiurus melas*	Yes	Not generally found with Shasta crayfish
	Mosquito fish	*Gambusia affinis*	No	Not generally found with Shasta crayfish
Benthic Invertebrates				
Crayfish	Signal crayfish	*Pacifastacus leniusculus*	Yes	Nonnative species; interferes with and replaces Shasta crayfish; potential to transmit pathogens and parasites to Shasta crayfish

Table 1. Animal and plant species associated with the Shasta crayfish in the Pit River and its subdrainages (Figures 1, 4, 5, and 8).

	Common Name	Scientific Name	Crayfish Predator	Comments
	Virile (fantail) crayfish	*Orconectes virilis*	Yes	Nonnative; potential competitor with Shasta crayfish; potential to transmit pathogens and parasites to Shasta crayfish
Mussels[2]	California floater	*Anodonta californiensis*		Federal species of concern
	Winged floater	*Anodonta wahlamatensis*		
	Oregon floater	*Anodonta oregonensis*		
	Montane peaclam	*Pisidium ultramontanum*		Federal species of concern
	Western ridgemussel	*Gonidea angulata*		
	Western pearshell	*Margaritifera falcata*		
Snails		*Juga acutifilosa*		Abundant and commonly found in spring areas; generally found on lava substrate; Shasta crayfish fed on snails in this genus in captivity
		Fluminicola seminalis		Abundant and commonly found in spring areas; found on green algae (*Rhizoclonium hookeri*, but not *Spirogyra* spp.); Shasta crayfish observed feeding on snails in this genus[3] in the field and in captivity
		Lanx patelloides		

[2] Signal crayfish were observed eating mussels (M. Ellis, pers. observ.)

[3] T. Light 1990, unpubl. field notes

Table 1. Animal and plant species associated with the Shasta crayfish in the Pit River and its subdrainages (Figures 1, 4, 5, and 8).

	Common Name	Scientific Name	Crayfish Predator	Comments
		Physella gyrina		Associated with fine sediment in larger lakes and rivers
		Helisoma newberryi		Associated with fine sediment in larger lakes and rivers
		Vorticifex effusa		
Birds[4]	Great blue heron	*Ardea herodias*	Yes	
	Belted kingfisher	*Ceryle alcyon*	Yes	
	Green-backed heron	*Butorides striatus*	Yes	
	Black-crowned night heron	*Nycticorax nycticorax*	Yes	
	American bittern	*Botaurus lentiginosus*	Yes	
	Bufflehead	*Bucephala albeola*	Possible	
	Common goldeneye	*Bucephala clangula*	Possible	
	Ring-necked duck	*Aythya collaris*	Possible	
	Western grebe	*Aechmophorus occidentalis*	Possible	
	Pied-billed grebe	*Podilymbus podiceps*	Possible	
	Double-crested cormorant	*Phalacrocorax auritus*	Possible	

[4] Tack 1941, Lagler and Lagler 1944

Table 1. Animal and plant species associated with the Shasta crayfish in the Pit River and its subdrainages (Figures 1, 4, 5, and 8).

	Common Name	Scientific Name	Crayfish Predator	Comments
	Sora	*Porzana carolina*	Possible	
	Virginia rail	*Rallus limicola*	Possible	
	Spotted sandpiper	*Actitis macularia*	Possible	
Mammals[5]	River otter	*Lutra canadensis*	Yes	
	Mink	*Mustela vison*	Yes	
	Beaver	*Castor canadensis*	No	Herbivorous, not likely to impact crayfish
	Muskrat	*Ondatra zibethica*	Yes	Destabilize banks and increase sediment
	Raccoon	*Procyon lotor*	Yes	
Amphibians[6]	Bullfrog	*Rana catesbeiana*	Yes	Introduced and now common in Crystal Lake and Big Lake
Reptiles[7]	Western pond turtle	*Clemmys marmorata*	Possible	
	Garter snake	*Thamnophis* spp.	Yes	

[5] Errington 1941; Burt and Grossenheider 1976; MacDonald 1985; Hanson *et al.* 1989; M. Ellis, pers. observ.
[6] Tack 1941, Penn 1950, Stebbins 1985
[7] Tack 1941, Lagler and Lagler 1944

Table 1. Animal and plant species associated with the Shasta crayfish in the Pit River and its subdrainages (Figures 1, 4, 5, and 8).

	Common Name	Scientific Name	Crayfish Predator	Comments
Aquatic Vegetation[8]	Filamentous green algae	*Rhizoclonium* spp.	--	Spring species; dominant vegetation in headwater spring areas where most Shasta crayfish populations are found; Shasta crayfish observed feeding on strand of dead aquatic vegetation thought to be in this genus[9]
	Buttercup	*Ranunculus* spp.	--	Spring species; patchy and covers small amounts of habitat
	Water-milfoil	*Myriophyllum* spp.	--	Spring species; patchy and covers small amounts of habitat
	Filamentous green algae	*Spirogyra* spp.	--	Covers large areas in Little Tule, Tule, and lower Fall Rivers; usually found in nutrient-rich eutrophic waters; not generally found with Shasta crayfish
	Waterweed	*Elodea* spp.	--	River species; found in Fall, Tule, and Little Tule rivers; and near shores of Pit 1 Forebay, Fall River Pond, Big Lake; some below Pit 1 Powerhouse

[8] Ellis and Hesseldenz 1993

[9] J. Clarke, unpubl. field notes

Table 1. Animal and plant species associated with the Shasta crayfish in the Pit River and its subdrainages (Figures 1, 4, 5, and 8).

Common Name	Scientific Name	Crayfish Predator	Comments
Horned-pondweed	*Zannichellia* sp.	--	River species; found in Fall, Tule, and Little Tule Rivers and near shores of Pit 1 Forebay, Fall River Pond, Big Lake; some below Pit 1 Powerhouse
Hornwort	*Ceratophyllum* spp.	--	Associated with streambanks in Big Eddy pool above the Pit River Canyon and Pit 1 Forebay

E. Habitat and Ecosystem

Physical Environment

Geologic Background. The past and present distribution of the Shasta crayfish is integrally tied to the geologic history of the Modoc Plateau, an immense lava field covering most of northeastern California. Because volcanic rock is porous, most rainfall percolates through the lava into the groundwater. Surface water is minimal, so rainfall from over 80 kilometers (50 miles) away and snowmelt from Lassen Peak, Medicine Lake Highlands, and other lesser peaks feed the groundwater that comes to the surface at contact springs (formed where permeable lava flows overlie less-permeable material such as lakebed sediment) in the midsections of the Pit River drainage (Norris and Webb 1990, Rose *et al.* 1996). The midsections of the Pit River drainage lie along the western margin of the Modoc Plateau geomorphic province.

Evidence from a recent study indicates that the Lassen volcanic highlands are the recharge area (source of water) for springs where Shasta crayfish are found in the Hat Creek Basin (Rose *et al.* 1996). Precipitation on the Lassen volcanic highlands percolates through the lava into a large central aquifer system underlying Hat Creek Valley, which supplies water to Rising River and Crystal Lake springs. The hydrologic features of the Fall River spring system are very similar to those of the Hat Creek basin springs. Preliminary data indicate that the Medicine Lake Highlands are the source of water for the Fall River springs (Rose *et al.* 1996). The Fall River and Rising River subdrainages, and to a lesser extent Hat Creek and the midsections of the Pit River, are characterized by extensive cold water springs (9–12 degrees Celsius; 48.2–53.6 degrees Fahrenheit). The volcanic origin of the area is also responsible for the dominant feature of Shasta crayfish habitat: lava cobble and boulders.

The second major geologic feature that determines the location of many of the springs in the area is the extensive deposits originating from large prehistoric lakes (Pleistocene/Pliocene). The Fall River and Hat Creek basins were part of a large lake or series of lakes that connected the Klamath Basin, in Oregon, and northern California (Russell 1885, Meinzer 1922, Hanna and Gester 1963). These prehistoric lakes also feature prominently in the zoogeography (animal distribution) of the region (Taylor and Smith 1981, Taylor 1985).

Drainage Description. The Pit River, which drains most of northeastern California, meanders through marshy pasture along the broad, low-gradient valley floors of its upper drainage in Lassen and Modoc Counties. Although the tributary streams of the upper Pit River are precipitous, cold and clear, the upper Pit River is often multichanneled, slow flowing, warm, and turbid. The upper river once flowed through indefinite channels creating extensive marshlands through the valleys in its upper drainage (Moyle and Daniels 1982). Most of these marshlands, however, have now been drained, with 20–25 percent of the water diverted for irrigation and the river and lowland portions of the tributaries channelized (Moyle and Daniels 1982).

The character of the Pit River changes below the mouth of Fall River, one of its largest tributaries. The Fall River is renowned for its size, flow, and clarity, which result from countless springs throughout its upper sections (Figure 3). Historically, the Fall River flowed over a series of falls into the Pit River at Fall River Mills. Now, virtually all of the Fall River's flow is diverted through the Pit 1 Powerhouse and enters the Pit River 10 kilometers (6.2 miles) below the point where the two rivers originally merged (Figure 1). At present, there are no regular releases of water into the 350-meter (0.2-mile) section of the Fall River channel upstream from the Pit River. The only water in this section downstream from the Fall River Weir (concrete dam with gates) is from seepage, except during occasional floods and spills. Below the historic mouth of Fall River, the Pit River

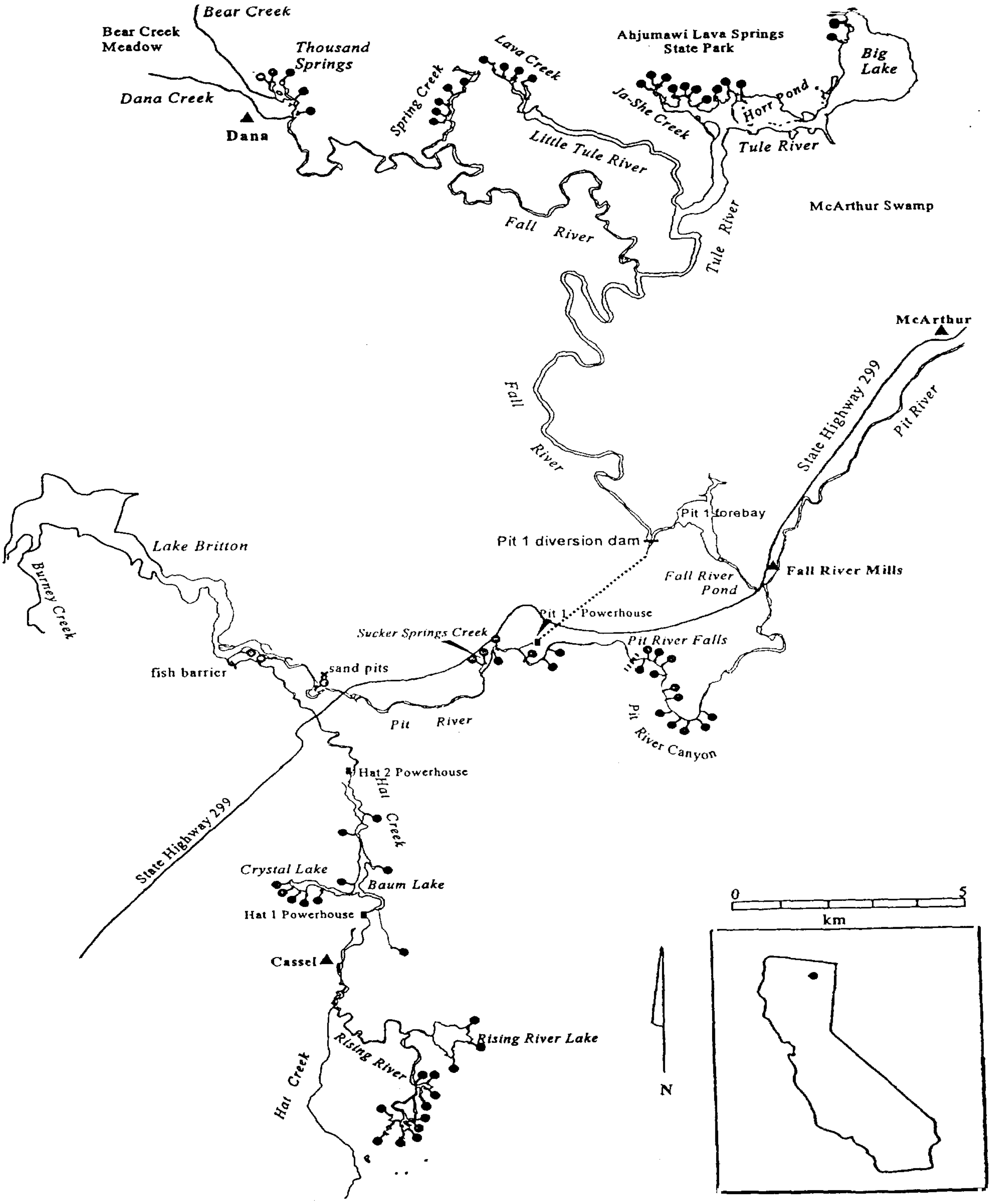

Figure 3. Distribution of springs in the midsections of the Pit River drainage.

is fed by numerous small springs as it flows through 7 kilometers (4.3 miles) of steep-walled, moderate-gradient canyon and over the Pit River Falls, which are approximately 12 meters (40 feet) high (Figure 3). After the springs in the Pit River canyon (Figure 3) and the water from Fall River (via the Pit 1 Powerhouse) contribute their cooling flows, the Pit River becomes a rapid, high-volume, moderately cold-water river. Water enters the Pit River downstream of the Pit 1 Powerhouse from several springs, including three major spring-fed tributaries: Sucker Springs Creek, Hat Creek, and Burney Creek (Figure 1). Hat Creek is the largest of these tributaries; the majority of its water comes from the Rising River subdrainage, whose springs are sustained by snowmelt from the Lassen Volcanic National Park area (Rose *et al.* 1996).

Fall River and Hat Creek are the two major subdrainages in the middle section of the Pit River drainage. Both of these subdrainages are predominately spring-fed. Fall River originates at Thousand Springs (Figure 1). The only above-ground tributaries to the Fall River are Bear and Dana Creeks. The channel of the lower Fall River (below its confluence with the Tule River) (Figure 1) is much wider than that of the upper Fall River, due to a broader floodplain and higher flows. Tule River receives its water from springs in its upper sections, including Big Lake and Ja-She Creek (Figure 1). Lava Creek and Eastman Lake are the spring-fed headwaters of the Little Tule River. The Tule River and upper Fall River each generally contribute about half of the 700–1,500 cubic feet per second (cfs) total flow in the lower Fall River.

The headwaters of Hat Creek, and its tributary Lost Creek, are on the lower north slope of Lassen Peak. Both streams are fed by snowmelt and small springs. For most of the year, the upper 61 kilometers (38 miles) of Hat Creek above its confluence with Rising River remains a small meandering stream. The majority of water in lower Hat Creek comes from Rising River and its tributary Rising River Lake (Figure 1). Like the Fall River, Rising River originates as a series of large springs on the edge of a lava field. Hat Creek is diverted to Hat 1 Powerhouse about 1.0 kilometer (0.6 mile) below its confluence with Rising River at the town of Cassel. About 5.5 kilometers (3.4 miles) of Hat Creek below Hat 1 Powerhouse is now impounded to form Baum Lake, which is the reservoir for Hat 2 Powerhouse (Figure 1).

The second major source of spring water in lower Hat Creek is Crystal Lake, which flows into Baum Lake. The Crystal Lake Fish Hatchery, operated by the California Department of Fish and Game, is located near the confluence of Crystal and Baum Lakes. Below Baum Lake the majority of Hat Creek is diverted through a concrete flume to Hat 2 Powerhouse. The 5.6-kilometer (3.5-mile) section of Hat Creek below Hat 2 Powerhouse has been managed as a wild trout stream since 1968. A 3-meter (9.8-foot)-high fish barrier prevents the movement of both nongame species and trout from Lake Britton into the wild trout area of Hat Creek.

Aquatic Environment

Shasta crayfish are generally found in the cold, clear, spring-fed headwaters of the midsections of the Pit River drainage, particularly in the headwaters of the Fall River subdrainage. In general, Shasta crayfish habitat is defined by the availability of cover, or refugia (protected places), provided by clean lava cobbles and boulders on gravel or sand. Although potential food resources, temperature, and water chemistry constituents (e.g., dissolved oxygen, calcium, pH) may also limit the distribution of Shasta crayfish, the range of these conditions where Shasta crayfish are found is considerable.

Substrate. During the Pit 1 rare species study (Ellis and Hesseldenz 1993), substrate was identified as silt, sand, Bear Creek gravel, lava gravel, lava cobbles, lava boulders, lava bedrock, diatomaceous earth/clay (earth composed of the shells of diatoms, a type of unicellular algae), or earthen clumps. Substrate in the upper Fall River consisted predominantly of fine sediment (sand and silt) with patches of lava cobbles and gravel. Portions of this section have received significant deposits of sediment, both fine and coarse material, from Bear Creek during high-flow events in some winters. Sedimentary materials from Bear Creek have created extensive beds of gravel that cover 94 percent of the upper river channel from Bear Creek to Read's Bridge (Figure 4). Below the mouth of Bear Creek, the gravel covers the west side of the river channel for 0.8 kilometer (2,600 feet) downstream to the Navigation Limit (the southern boundary of Section 19, Township 38 North, Range 4 East). This shallow, 0.10–0.75-meter (4–30-inch)-deep segment of river constitutes the only moderate-gradient section of the entire Fall River. At the Navigation Limit the river bends to the west, and Bear Creek gravel extends completely across the river, burying most lava substrate. Sand and silt from the Bear Creek drainage, and local erosion, cover portions of the Fall River channel. The substrate in the lakes and reservoirs consists primarily of fine organic sediment with little to no natural lava substrate except in spring areas. Lava, however, was imported along the levees of Big Lake and parts of the Tule River during some periods of levee maintenance.

Tule River, Little Tule River, and lower Fall River (below the mouth of Tule River) are variable-temperature, slow-moving, low-gradient rivers that are characterized by seasonal variations in temperature (5–23 degrees Celsius [41–73 degrees Fahrenheit]) and turbidity, with warm eutrophic water (nutrient-rich and low in oxygen) in the summer (Ellis and Hesseldenz 1993). These rivers are moderately wide with an average depth of 2.5–3.0 meters (8–10 feet). The substrate in these rivers is predominantly silt and fine organic matter. Although there is little to no natural lava substrate, some lava was imported into these rivers for levee maintenance and bridge construction.

The Pit River is a variable-temperature (5–23 degrees Celsius [41–73 degrees Fahrenheit]), moderate-gradient (1.6 percent slope) river from its entrance into the

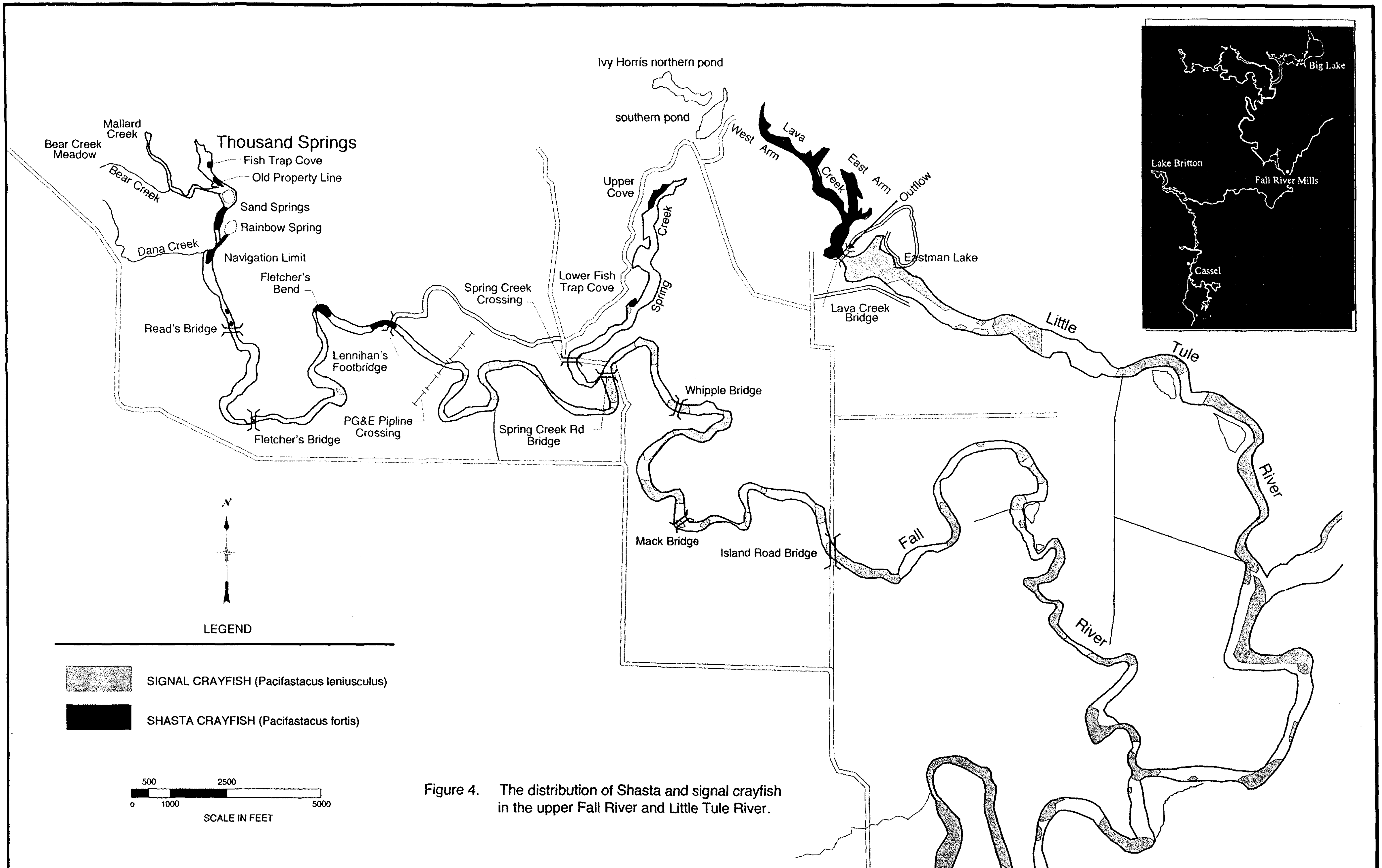

Figure 4. The distribution of Shasta and signal crayfish in the upper Fall River and Little Tule River.

canyon at Big Eddy, 3.6 kilometers (2.2 miles) below the mouth of Fall River, to Lake Britton, 14.2 kilometers (8.8 miles) downstream (Figure 5). The substrate in the Pit River consists predominantly of large boulders.

Fish. The fish community in the midsections of the Pit River drainage comprises both native and nonnative species. The fish community in the spring areas is composed of predominantly native species (Table 1). Chinook salmon (*Oncorhynchus tshawytscha*) were found in the Pit River prior to the completion of downstream hydroelectric dams. Spring runs of chinook ascended the Pit River into Hat Creek and some even passed the Pit River Falls to ascend the Fall River to its source near Dana (Rutter 1903).

Benthic Invertebrates. The midsections of the Pit River drainage support a diverse community of benthic (bottom-living) invertebrates (Table 1), including the Shasta crayfish and two introduced species of crayfish. There is a diverse freshwater molluscan community. Several species of snails are associated with the spring-fed headwater areas. Extensive middens, or waste piles, of freshwater mussel shells are found throughout the drainage, especially along Big Lake and Tule River. These middens reflect both muskrat predation and the long-time history of mussel use by the Achumawi and Atsugewi tribes.

Aquatic Vegetation. Aquatic vegetation (Table 1) in the spring areas of the Pit River drainage covered 0–35 percent of the bottom (benthic coverage) (Ellis and Hesseldenz 1993). Aquatic vegetation covered much of the bottom in the manmade reservoirs such as Pit 1 Forebay and Fall River Pond, ranging between 30 to 95 percent; in the rivers, coverage ranged from 15 to 25 percent (Ellis and Hesseldenz 1993). The vegetation in the upper Fall River was a mix of spring-type vegetation (i.e., *Myriophyllum* and *Rhizoclonium*) and river-type vegetation (i.e., *Elodea* and *Zannichellia*). Vegetation covered about 30 percent of the upper

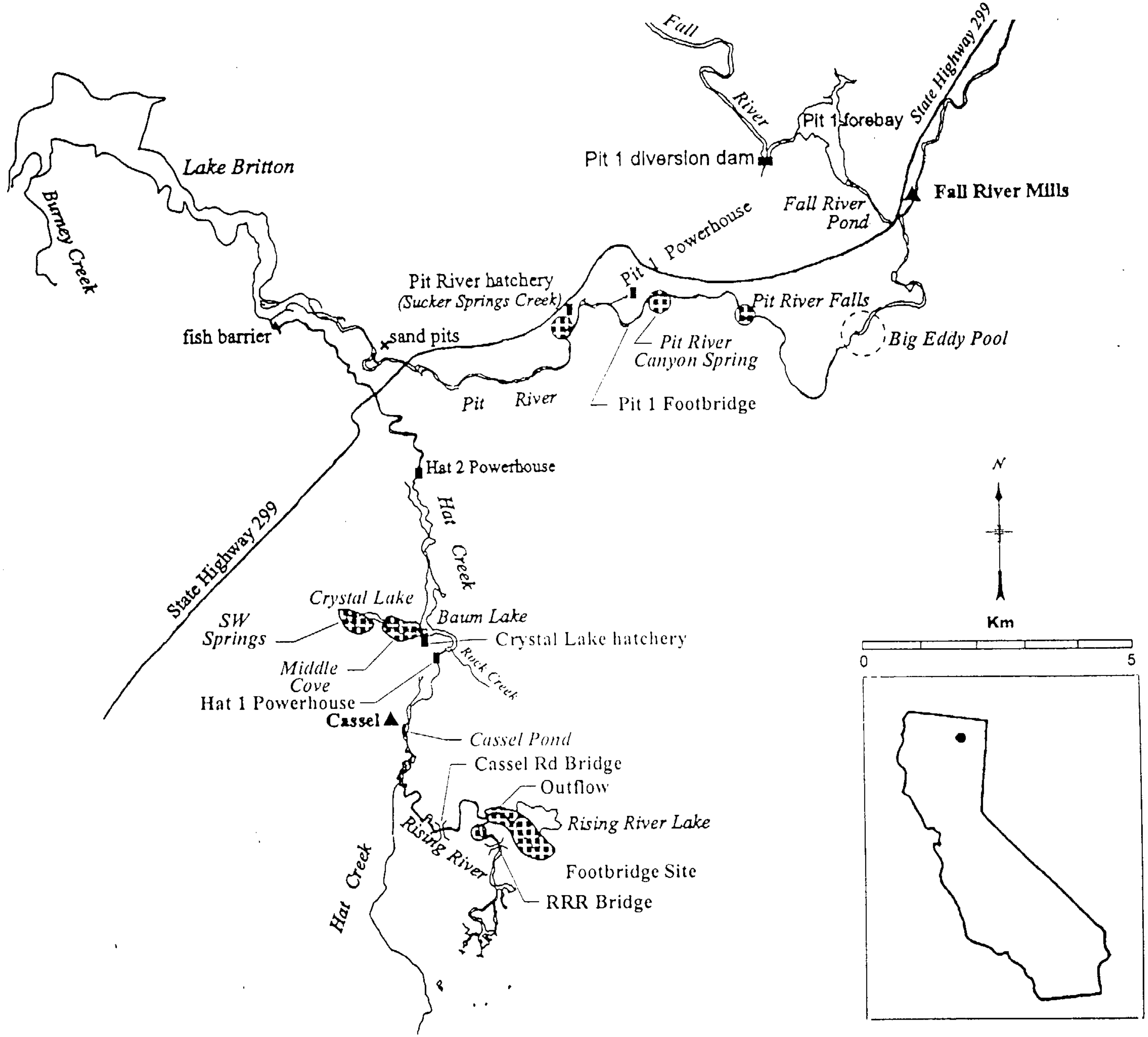

Figure 5. Distribution of Shasta cray ... n the Pit River and Hat Creek Area

Fall River (Ellis and Hesseldenz 1993). In 1992, small patches of spring-type vegetation occurred in the upper Fall River above the PG&E Pipeline crossing, while extensive beds of *Elodea* and *Zannichellia* dominated the river channel downstream (Ellis and Hesseldenz 1993). Significant amounts of aquatic vegetation did not occur in the Pit River canyon upstream of the Pit 1 Powerhouse. Above the canyon in Big Eddy pool, there were patches of *Ceratophyllum* associated with the streambanks. There were a few extensive beds of *Elodea* and *Zannichellia* in the Pit River downstream of the Pit 1 Powerhouse.

F. Distribution and Population Status

To discuss historic and current population status as well as restoration and recovery, Shasta crayfish are divided into populations and subpopulations. The historic range of the Shasta crayfish (Figure 6) refers to the limits of its geographical distribution and does not imply that species distribution was continuous across the range.

E.O. Wilson (1992) states that a clearly defined population occupies an exclusive part of the range of the species. Wilson also cautions that few such objectively definable populations exist in nature, except for endangered species having so few organisms left that there is no doubt as to the boundaries of the population. Furthermore, populations can expand, contract, and reform so the boundaries are not static.

A population of Shasta crayfish is defined as all Shasta crayfish occupying a defined area that is isolated from other similar groups (see Lincoln *et al.* 1982). Either physical barriers or distance isolate these populations and preclude all genetic exchange between populations. Many of the Shasta crayfish populations are divided into two or more subpopulations. These subpopulations occupy a

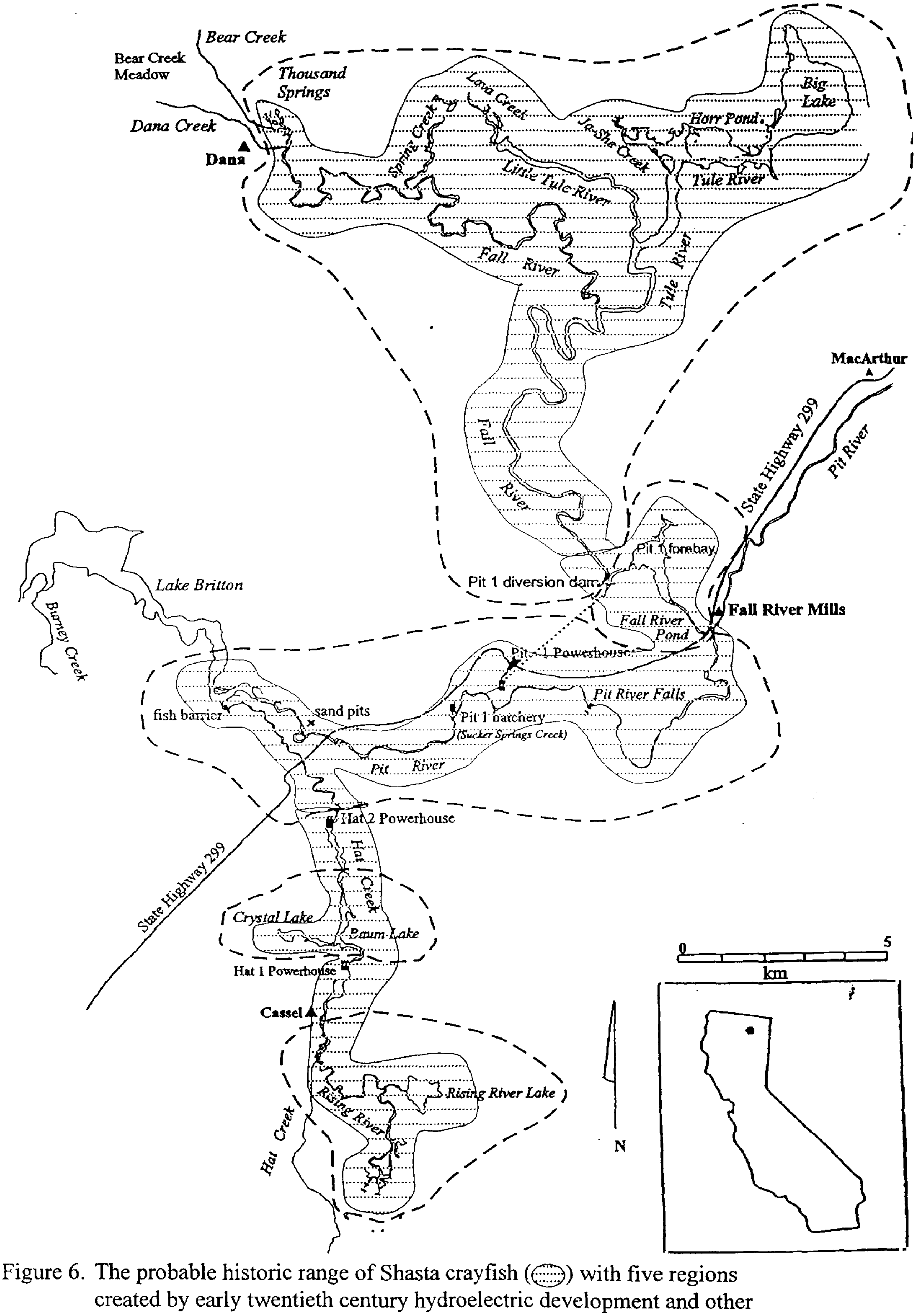

Figure 6. The probable historic range of Shasta crayfish (⊜) with five regions created by early twentieth century hydroelectric development and other disturbances (— —).

distinct and exclusive part of the population area and are isolated to some degree from other subpopulations. Genetic exchange probably occurs between some subpopulations, at least in a downstream direction.

Historic Distribution

Although it is impossible to determine the exact historic range and distribution of the Shasta crayfish, information on the ancestral range may be derived from the study of the distribution (zoogeography) and history of crayfish collections in this region. The unique volcanic and spring environment of this area (Figure 3) supports a number of rare and endemic species, including sculpin and molluscs found only within the Fall River system and a few nearby springs in the Hat Creek and Pit River drainages (Moyle and Daniels 1982, Taylor 1981). This distinct zoogeographical region is defined by a constant supply of cold, clear, spring water and lava substrate. These habitat conditions do not occur in Bear Creek or the Pit River above the mouth of Fall River and are less common in the Pit River below the mouth of Burney Creek and in Hat Creek upstream of the Rising River.

Shasta crayfish are considered a relict species, a species surviving from a much earlier geologic era, whose ancestral range was reduced by geologic and related climatic changes (Bouchard 1978). Historic and zoogeographical evidence, however, indicates that the historic range (i.e., the limits of the geographic distribution) of the Shasta crayfish has remained relatively unchanged during the period of recorded history (Ellis, submitted). All known collections of Shasta crayfish are within the limits of their current range.

Although the limits of its range appear to be relatively unchanged in historical times, the distribution of Shasta crayfish within that range is probably more fragmented than it was historically. Shasta crayfish, however, were probably never continuously distributed throughout their range. The strong correlation between Shasta crayfish and lava substrate, and the discontinuous distribution of lava substrate in the drainage, indicate that the distribution of Shasta crayfish was most likely always patchy. The distribution of Shasta crayfish has become patchier because large areas of lava substrate have become unavailable to Shasta crayfish during this century as a result of habitat alterations (e.g., excavations, impoundments, water diversions, and sedimentation) and the colonization of lava substrate by introduced crayfish.

Many of the disjunct populations of Shasta crayfish are isolated not only by distance, but by natural barriers or by manmade barriers, such as hydroelectric development. Given that Shasta crayfish once occurred in the Fall River at Fall River Mills and probably occurred in the mainstem Hat Creek near Cassel (Faxon 1914), it is likely that Shasta crayfish occurred at other sites between present population locations.

Although Shasta crayfish are not known to move great distances from their habitat, they have dispersed into and colonized new areas when habitat was created by the addition of lava substrate, such as around bridge abutments and the levees in the upper Tule River subdrainage (upper Tule River refers to the section of river that widens around Horr Pond and continues to Big Lake). In some cases, Shasta crayfish may have had to move through areas without lava substrate to reach new habitat. Even though Shasta crayfish probably did not occupy nonlava substrate areas, dispersal through these areas would have played a key role in gene flow (i.e., the exchange of genetic material between populations through interbreeding) and allowed maximum use of islands of lava substrate. Periodic dispersal of a few individuals from another location, even if restricted to downstream migration, could result in adequate gene flow to maintain the genetic variability of the species. The loss of lava substrate in historic times has restricted the dispersal of Shasta crayfish, isolated subpopulations, and created disjunct populations.

Additional evidence of the historic distribution of Shasta crayfish has been derived from the historical food habits of two major tribes of Pit River Indians, the Achumawi (Fall River and south side of the Pit River) and Atsugewi (Hat Creek), who used crayfish as a food supply (Voegelin 1942). These Native Americans built stone fish traps in the shallow spring areas of the Fall and Pit Rivers to catch Sacramento suckers (*Catostomus occidentalis*) during spawning (Evans 1987, Dreyer and Johnson 1988). The stone fish traps in the headwaters of the Fall River had the greatest densities of Shasta crayfish because the lava boulder and cobble walls and lava cobble and gravel substrate of the traps provided excellent habitat for Shasta crayfish. Although there is little information on the use of crayfish by early Americans, the available data give no indication of a broader historic range for the Shasta crayfish. No crayfish were reported in the native environment along the upper Pit River (Voegelin 1942).

Current Distribution

The Hat Creek mudflow of 1915, which was triggered by an eruption of Lassen Peak, resulted in a massive fish kill throughout the mainstem of Hat Creek (Merrill 1916, Bryant 1918, California Department of Fish and Game 1920). This mudflow would have isolated Shasta crayfish in the tributaries of Hat Creek by destroying Shasta crayfish and Shasta crayfish habitat in the mainstem of Hat Creek. The development of the Pit 1 and Hat Creek hydroelectric projects in 1920–1922 separated (1) the Fall River drainage from the Pit River; (2) the Pit River from most of the Hat Creek drainage; and (3) the middle section of the Hat Creek drainage, including Rock Creek and Crystal Lake, from the Rising River subdrainage and upper Hat Creek (Figure 6).

The range of the Shasta crayfish was divided into at least five areas that were geographically isolated by major physical barriers created during the hydroelectric development of the area (Figure 6): (1) the Fall River drainage upstream from the

Pit 1 Diversion Dam; (2) the Fall River between the Pit 1 Diversion Dam and the Fall River Weir; (3) the Pit River, including Sucker Springs Creek and lower Hat Creek downstream from the Hat 2 Powerhouse; (4) Crystal and Baum Lakes and Rock Creek; and 5) the Rising River subdrainage and Hat Creek upstream of Cassel. In 1946, the Fall River was further divided by the construction of the Pit 1 Forebay Dam. In 1968, construction of a fish barrier dam just upstream from the mouth of Hat Creek further divided Hat Creek and the Pit River. This dam created a waterfall that prevented fish from moving upstream from Lake Britton into Hat Creek (M. Ellis, pers. comm.).

As a result of construction of these physical barriers and other disturbances that created large stretches of unsuitable habitat, Shasta crayfish currently were isolated geographically into eight populations (Figure 7); however, only seven populations remain in existence. The Fall River population, which was probably originally much more continuous than present, is now separated into four geographically isolated populations: (1) upper Fall River, (2) Spring Creek, (3) Lava Creek, and (4) upper Tule River, including Ja-She Creek, upper Tule River, and Big Lake. The (5) Fall River, Fall River Mills population is considered extirpated (i.e., no longer exists). The remaining populations include the (6) Pit River, (7) Hat Creek, Cassel, and (8) Rising River populations. The seven existing populations comprise several locations or subpopulations that may or may not have genetic exchange through interbreeding (Table 2).

The first comprehensive survey of Shasta crayfish was conducted by Daniels (1980, Eng and Daniels 1982). In 1990, PG&E initiated the most thorough and extensive surveys ever undertaken in the area (Ellis 1991a, 1993a, 1994a, 1995, 1996a, 1996b, Hesseldenz and Ellis 1991, Ellis and Hesseldenz 1993). Ellis (1996c) provides an in-depth history of all investigations involving Shasta crayfish and a history and list of all known museum collections of Shasta crayfish.

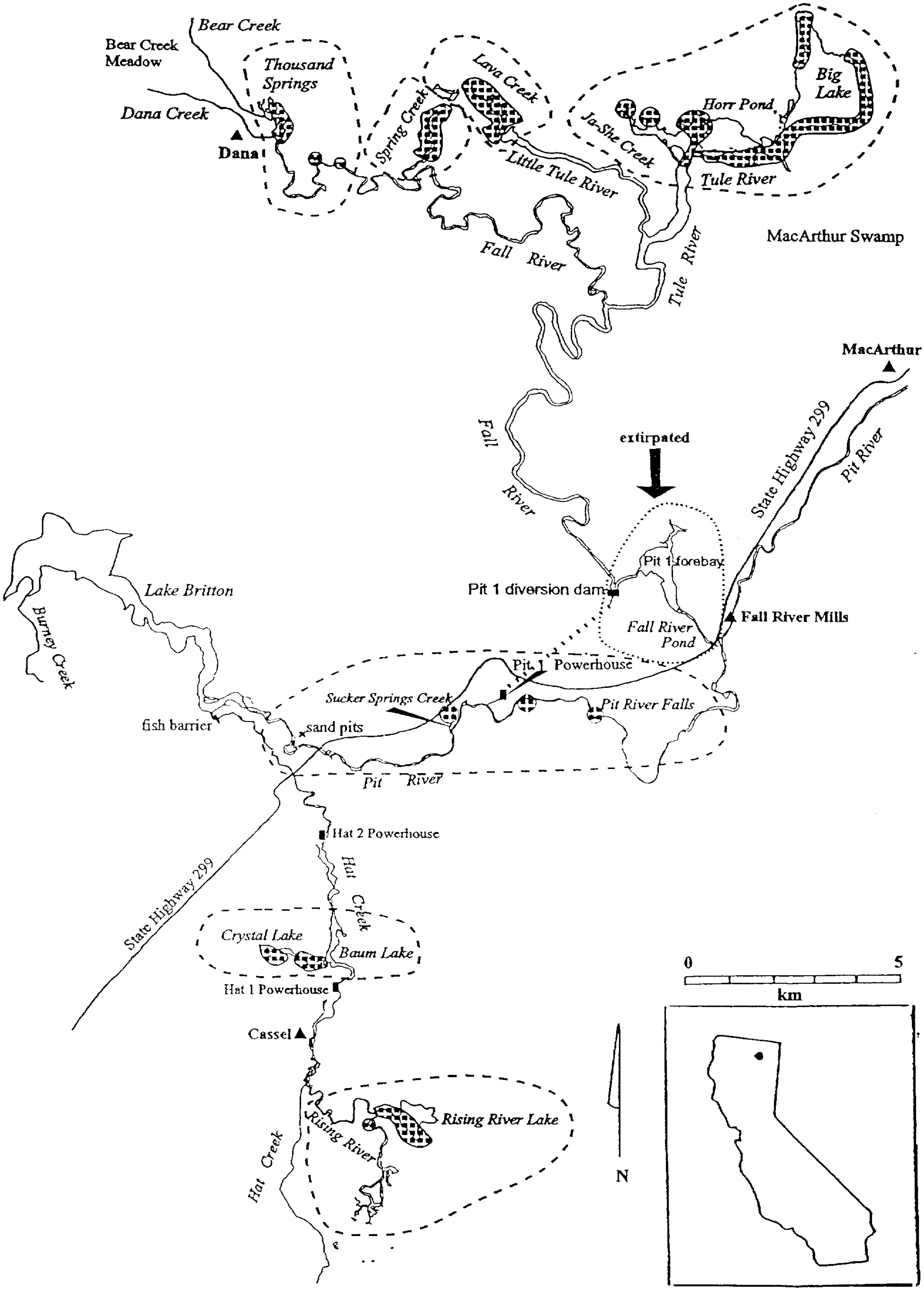

Figure 7. Location of the eight geographically isolated populations of Shasta crayfish.

Table 2. Shasta crayfish population status [1], ownership, threats, and suggested restoration actions (Figures 4, 5, and 8).

Population Subpopulation	Status[2]	Nonnative Invasion[3]	Owner	Threats	Suggested Restoration
Upper Fall River					
Thousand Springs fish trap cove	S	N	Private, restricted access; managed as wildlife refuge	Signal crayfish invasion	Install barrier at Navigation Limit; support landowner's management
Thousand Springs old property line	S	N	Private, restricted access; managed as wildlife refuge	Signal crayfish invasion	Install barrier at Navigation Limit; support landowner's management
Fall River sand springs	S	N	Private, restricted access	Signal crayfish invasion; Bear Creek gravel and sediment	Install barrier at Navigation Limit; support landowner's management; restore Bear Creek meadow
Rainbow Spring	PS	N	Private, restricted access	Signal crayfish invasion	Install barrier at Navigation Limit
Fall River above Navigation Limit	S or D	Y(SC)	Private, restricted access	Bear Creek gravel and sediment; shortage of non-embedded lava substrate; further invasions and interactions with signal crayfish	Install barrier at Navigation Limit; restore Bear Creek meadow; uncover embedded lava substrate
Fall River below Navigation Limit	NS	Y(SC)	Private, navigable	--	--

[1] Population status and the presence of non-native crayfish species as of surveys conducted between 1991 - 1995
[2] S= stable; D= decreasing; PS= presumed stable (last surveyed 1985); NS= not self-sustaining; PE = presumed extirpated; E= extirpated; ID = insufficient data
[3] N=no; Y=yes; SC=signal crayfish; VC= virile crayfish

Table 2. Shasta crayfish population status [1], ownership, threats, and suggested restoration actions (Figures 4, 5, and 8).

Population Subpopulation	Status[2]	Nonnative Invasion[3]	Owner	Threats	Suggested Restoration
Fall River at Fletcher's Bend	D	Y(SC)	Private, navigable	Bear Creek sediment; shortage of non-embedded lava substrate; further invasions and interactions with signal crayfish	Restore Bear Creek meadow; add lava cobbles and boulders; install exclusion fencing along Fall River
Fall River at Lennihan's Footbridge	D	Y(SC)	Private, navigable	Bear Creek sediment; shortage of non-embedded lava substrate; further invasions and interactions with signal crayfish	Restore Bear Creek meadow; add lava cobbles and boulders; install exclusion fencing along Fall River
Spring Creek					
Upper coves	S	N	Private, restricted access; managed as wildlife refuge	Signal crayfish invasion	Fortify barrier at Spring Creek Road crossing (culverts), continue signal crayfish eradication upstream
Lower fish trap cove	S	N	Private, restricted access; managed as wildlife refuge	Signal crayfish invasion; shortage of lava cobble/boulder substrate	Fortify barrier at Spring Creek Road crossing; add lava cobbles and boulders, continue signal crayfish eradication upstream

[1] Population status and the presence of non-native crayfish species as of surveys conducted between 1991 - 1995
[2] S= stable; D= decreasing; PS= presumed stable (last surveyed 1985); NS= not self-sustaining; PE = presumed extirpated; E= extirpated; ID = insufficient data
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Table 2. Shasta crayfish population status[1], ownership, threats, and suggested restoration actions (Figures 4, 5, and 8).

Population Subpopulation	Status[2]	Nonnative Invasion[3]	Owner	Threats	Suggested Restoration
Lava Creek					
Ivy Horr's northern pond	E	N	Private, restricted access; managed as wildlife refuge	Introduced largemouth bass	
Lava Creek east arm	S or D	N?	Private, restricted access; managed as wildlife refuge	Signal crayfish invasion	Install barrier at outflow; support landowner's management
Lava Creek west arm	S or D	N?	Private, restricted access; managed as wildlife refuge	Signal crayfish invasion	Install barrier at outflow; support landowner's management
Between confluence of arms and outflow	D	Y(S)	Private, restricted access; managed for fly-fishing	Further invasions and interactions with signal crayfish	Install barrier at outflow; support landowner's management; signal crayfish eradication
Lava Creek outflow	D	Y(SC)	Private, restricted access; managed for fly-fishing	Further invasions and interactions with signal crayfish	Install barrier at outflow; signal crayfish eradication

[1] Population status and the presence of non-native crayfish species as of surveys conducted between 1991 - 1995
[2] S= stable; D= decreasing; PS= presumed stable (last surveyed 1985); NS= not self-sustaining; PE = presumed extirpated; E= extirpated; ID = insufficient data
[3] N=no; Y=yes; SC=signal crayfish; VC= virile crayfish

Table 2. Shasta crayfish population status [1], ownership, threats, and suggested restoration actions (Figures 4, 5, and 8).

Population Subpopulation	Status[2]	Nonnative Invasion[3]	Owner	Threats	Suggested Restoration
Upper Tule River					
East shore upper Tule River	D	Y(SC)	PG&E; managed for seasonal cattle grazing	Absence of lava substrate; dredging; further invasions and interactions with signal crayfish	Substrate additions to create habitat and stabilize levees; levee bank stabilization with native grasses; eliminate dredging
South shore upper Tule River	D	Y(SC)	PG&E; managed for seasonal cattle grazing	Absence of lava substrate; dredging; further invasions and interactions with signal crayfish	Substrate additions to create habitat and stabilize levees; levee bank stabilization with native grasses; eliminate dredging
South shore Big Lake	S or D	N? (1 VC in 1994)	PG&E; levees fenced; Wildlife Habitat Improvement Area (WHIP) and McArthur swamp managed for wildlife and seasonal cattle grazing	Further nonnative invasions/introductions and interactions; lava substrate shortage; dredging	Install barrier near Rat Farm; substrate additions to create habitat and stabilize levees; levee bank stabilization with native grasses; eliminate dredging; signal crayfish eradication
East Big Lake	S or D	N	PG&E (lake/riverbed)	Signal crayfish invasion	Install barrier near Rat Farm

[1] Population status and the presence of non-native crayfish species as of surveys conducted between 1991 - 1995
[2] S= stable; D= decreasing; PS= presumed stable (last surveyed 1985); NS= not self-sustaining; PE = presumed extirpated; E= extirpated; ID = insufficient data
[3] N=no; Y=yes; SC=signal crayfish; VC= virile crayfish

Table 2. Shasta crayfish population status [1], ownership, threats, and suggested restoration actions (Figures 4, 5, and 8).

Population Subpopulation	Status[2]	Nonnative Invasion[3]	Owner	Threats	Suggested Restoration
Northeast Big Lake	S	N	PG&E (lake/riverbed); CDPR (Ahjumawi Lava Springs SP)	Signal crayfish invasion	Install barrier near Rat Farm; substrate additions
North Big Lake	S	N	PG&E	Signal crayfish invasion	Install barrier near Rat Farm
Big Lake Springs	S	N	PG&E (lake/riverbed); CDPR (Ahjumawi Lava Springs SP)	Signal crayfish invasion	Install barrier near Rat Farm
Northwest Big Lake	S	N	PG&E (lake/riverbed); CDPR (Ahjumawi Lava Springs SP)	Signal crayfish invasion	Install barrier near Rat Farm; substrate additions
Northeast upper Tule River	D	Y(SC)	PG&E (lake/riverbed); CDPR (Ahjumawi Lava Springs SP)	Further signal crayfish invasions and interactions; virile crayfish invasion; absence of lava substrate	Install barrier near Rat Farm; substrate additions to create habitat and stabilize levees; signal crayfish eradication
Horr Pond levees	S	N	PG&E (riverbed on south side of levees); CDPR (Ahjumawi Lava Springs SP)	Signal crayfish invasion; absence of lava substrate	Substrate additions to create habitat
Tule Coves	S or D	Y(SC)	PG&E (lake/riverbed); CDPR (Ahjumawi Lava Springs SP)	Further signal crayfish invasions and interactions	Install barrier; signal crayfish eradication
Crystal Springs, Cove, and Inlet	S or D	Y(SC)	PG&E (lake/riverbed); CDPR (Ahjumawi Lava Springs SP)	Further signal crayfish invasions and interactions	Install barrier

[1] Population status and the presence of non-native crayfish species as of surveys conducted between 1991 - 1995
[2] S= stable; D= decreasing; PS= presumed stable (last surveyed 1985); NS= not self-sustaining; PE = presumed extirpated; E= extirpated; ID = insufficient data
[3] N=no; Y=yes; SC=signal crayfish; VC= virile crayfish

Table 2. Shasta crayfish population status [1], ownership, threats, and suggested restoration actions (Figures 4, 5, and 8).

Population Subpopulation	Status[2]	Nonnative Invasion[3]	Owner	Threats	Suggested Restoration
Ja-She Creek headwaters	S	N?	PG&E (water rights); CDPR (Ahjumawi Lava Springs SP)	Signal crayfish invasion	Install barrier at Ahjumawi SP Road crossing; signal crayfish eradication
Fall River, Fall River Mills					
Fall River Pond	PE	Y(SC/VC)	PG&E	--	--
Pit River					
Pit River Falls	ID	Y (VC)	PG&E	Interactions with virile crayfish; signal crayfish invasion; water quality	Determine distribution, abundance, and relative abundance in mainstem
Pit River Canyon spring	ID	Y(SC/VC)	PG&E	Interactions with virile and signal crayfish; water quality	Determine distribution, abundance, and relative abundance in mainstem
Sucker Springs, Pond 3	D	Y(SC)	PG&E	Signal crayfish invasions and interactions; shortage of lava cobble/boulder substrate	Install barrier at downstream end of Ponds 4 and 5; signal crayfish eradication; substrate additions

[1] Population status and the presence of non-native crayfish species as of surveys conducted between 1991 - 1995
[2] S= stable; D= decreasing; PS= presumed stable (last surveyed 1985); NS= not self-sustaining; PE = presumed extirpated; E= extirpated; ID = insufficient data
[3] N=no; Y=yes; SC=signal crayfish; VC= virile crayfish

Table 2. Shasta crayfish population status[1], ownership, threats, and suggested restoration actions (Figures 4, 5, and 8).

Population Subpopulation	Status[2]	Nonnative Invasion[3]	Owner	Threats	Suggested Restoration
Sucker Springs, Ponds 4 and 5	D	Y(SC)	PG&E	Shortage of lava cobble/boulder substrate; further signal crayfish invasions and interactions	Install barrier at downstream end of Pond 3; signal crayfish eradication; substrate additions
Pit River sand pits	E?	Y(SC)	PG&E	Interactions with signal crayfish; water quality	Determine distribution, abundance, and relative abundance in mainstem; install exclusion fencing
Hat Creek, Cassel					
Crystal Lake southwest springs	D	Y(SC)	PG&E	Further signal crayfish invasions and interactions	Install barrier at outflow; signal crayfish eradication; exclude or remove cattle from shoreline
Crystal Lake middle cove	D	Y(SC)	PG&E	Further signal crayfish invasions and interactions	Install barrier at outflow; signal crayfish eradication; exclude or remove cattle from shoreline

[1] Population status and the presence of non-native crayfish species as of surveys conducted between 1991 - 1995
[2] S= stable; D= decreasing; PS= presumed stable (last surveyed 1985); NS= not self-sustaining; PE = presumed extirpated; E= extirpated; ID = insufficient data
[3] N=no; Y=yes; SC=signal crayfish; VC= virile crayfish

Table 2. Shasta crayfish population status [1], ownership, threats, and suggested restoration actions (Figures 4, 5, and 8).

Population Subpopulation	Status[2]	Nonnative Invasion[3]	Owner	Threats	Suggested Restoration
Crystal Lake outflow	D	Y(SC)	PG&E	Further signal crayfish invasions and interactions	Install barrier at outflow; signal crayfish eradication; exclude or remove cattle from shoreline
Baum Lake	NS	Y(SC)	PG&E	--	--
Rock Creek	E	N	PG&E, CDFG diverts over 90% of water to Crystal Lake Fish Hatchery	Water diversion, fishery management	Release more water; possible Shasta crayfish refuge above diversion
Rising River					
Rising River Ranch Bridge	S or D?	N	Private, restricted access; managed as wildlife refuge	Signal crayfish invasion	Install barrier upstream of confluence with Hat Creek; support landowner's management
Rising River Footbridge	S or D?	N	Private, restricted access; managed as wildlife refuge	Signal crayfish invasion	Install barrier upstream of confluence with Hat Creek; support landowner's management
Rising River outflow channel	S	N	Private, restricted access; managed as wildlife refuge	Signal crayfish invasion	Install barrier upstream of confluence with Hat Creek; support landowner's management

[1] Population status and the presence of non-native crayfish species as of surveys conducted between 1991 - 1995
[2] S= stable; D= decreasing; PS= presumed stable (last surveyed 1985); NS= not self-sustaining; PE = presumed extirpated; E= extirpated; ID = insufficient data
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Table 2. Shasta crayfish population status[1], ownership, threats, and suggested restoration actions (Figures 4, 5, and 8).

Population Subpopulation	Status[2]	Nonnative Invasion[3]	Owner	Threats	Suggested Restoration
Rising River Lake	S or D?	N	Private, restricted access; managed as wildlife refuge	Signal crayfish invasion	Install barrier upstream of confluence with Hat Creek; support landowner's management

[1] Population status and the presence of non-native crayfish species as of surveys conducted between 1991 - 1995
[2] S= stable; D= decreasing; PS= presumed stable (last surveyed 1985); NS= not self-sustaining; PE = presumed extirpated; E= extirpated; ID = insufficient data
[3] N=no; Y=yes; SC=signal crayfish; VC= virile crayfish

Land Ownership. Most of the Shasta crayfish populations, including the largest populations, are located on private land. The largest landowner of waterfront property in the midsections of the Pit River drainage is probably PG&E, which owns property along the Pit River (including Sucker Springs Creek) and in the upper Tule River drainage and portions of the lower Hat Creek drainage (including property along Hat Creek, Crystal Lake, and Baum Lake). PG&E also leases some of its property to California Department of Fish and Game, including Sucker Springs Creek and property along Crystal and Baum Lakes to operate the Crystal Lake Fish Hatchery. California Department of Parks and Recreation owns land in the upper Tule River drainage (i.e., Ahjumawi Lava Springs State Park). Most of the Bear Creek drainage, which is managed as timberlands, is privately owned. Table 2 summarizes the status, land ownership, current threats, and suggested restoration actions for all populations of Shasta crayfish by geographic area, based on data collected during surveys conducted between 1991 and 1995.

Upper Fall River Population (Thousand Springs). The Fall River is fed by numerous springs from its origin at Thousand Springs and Dana (Figure 4). In addition, two surface runoff streams, Bear Creek and Dana Creek, join Fall River within the first 1.5 kilometers (0.9 mile) downstream of Thousand Springs. The tendency for flash flooding in these subdrainages and their potential for producing large amounts of sediments have negatively influenced some of the Shasta crayfish subpopulations in recent decades. Although the Shasta crayfish population in the upper Fall River is fragmented and divided into a number of disjunct subpopulations, genetic exchange is possible and even likely among some of these subpopulations. Genetic exchange between more distant subpopulations becomes increasingly doubtful. Because Shasta crayfish generally do not move great distances (Erman *et al.* 1993; M. Ellis, unpubl. data 1991, pers. observ.) except where they are washed downstream by the current, the occurrence of genetic exchange is probably greater in, if not restricted to, the downstream direction. Consequently, populations at the extreme ends probably are genetically distinct from each other.

Spring Creek Population. Spring Creek is a large, spring-fed tributary to the upper Fall River (Meinzer 1927) (Figure 4). The largest population of Shasta crayfish, estimated at over 4,000 individuals, is found in Spring Creek upstream of the four culverts at the Spring Creek Road crossing. Under normal flow conditions, the culverts at the Spring Creek Road crossing appear to create a combination physical/velocity barrier to the upstream invasion of signal crayfish, which were found immediately below the crossing.

Shasta crayfish were first reported at Spring Creek in 1978 (Daniels 1980). Shasta crayfish were found in the spring-fed coves with lava substrate on the western side of Spring Creek. Genetic exchange is probably occurring between crayfish in the upper coves (Erman *et al.* 1993). The distribution of both lava substrate and Shasta crayfish was probably once more continuous throughout Spring Creek than it is now.

Lava Creek Population. Four large, spring-fed, lava sinkhole pools feed into Lava Creek, which feeds into the Little Tule River at Eastman Lake. The east and west arms of the creek meet 500 meters (0.4 mile) above the Lava Creek outflow, the point where Lava Creek flows into Eastman Lake (Figure 4). Shasta crayfish have been found throughout Lava Creek wherever there was suitable lava habitat (Ellis 1996c). Because lava substrate is found throughout most of the stream, Shasta crayfish had an almost continuous distribution throughout Lava Creek as recently as 1991. When McGriff surveyed Lava Creek in 1985, the spillover into Eastman Lake seemed to act as a velocity barrier (i.e., the rate of water flow was apparently sufficient to prevent upstream migration of signal crayfish). McGriff found signal crayfish immediately below the outflow in Eastman Lake (D. McGriff, unpubl. data 1985).

Upper Tule River Population. The upper Tule River subdrainage is fed by two large spring-fed tributaries: Ja-She Creek (fed by Crystal Springs and Crystal Inlet and springs in the Ja-She Creek headwaters) and Big Lake (fed by Big Lake Springs and springs in North Big Lake) (Figure 8). The spring-fed Tule Coves

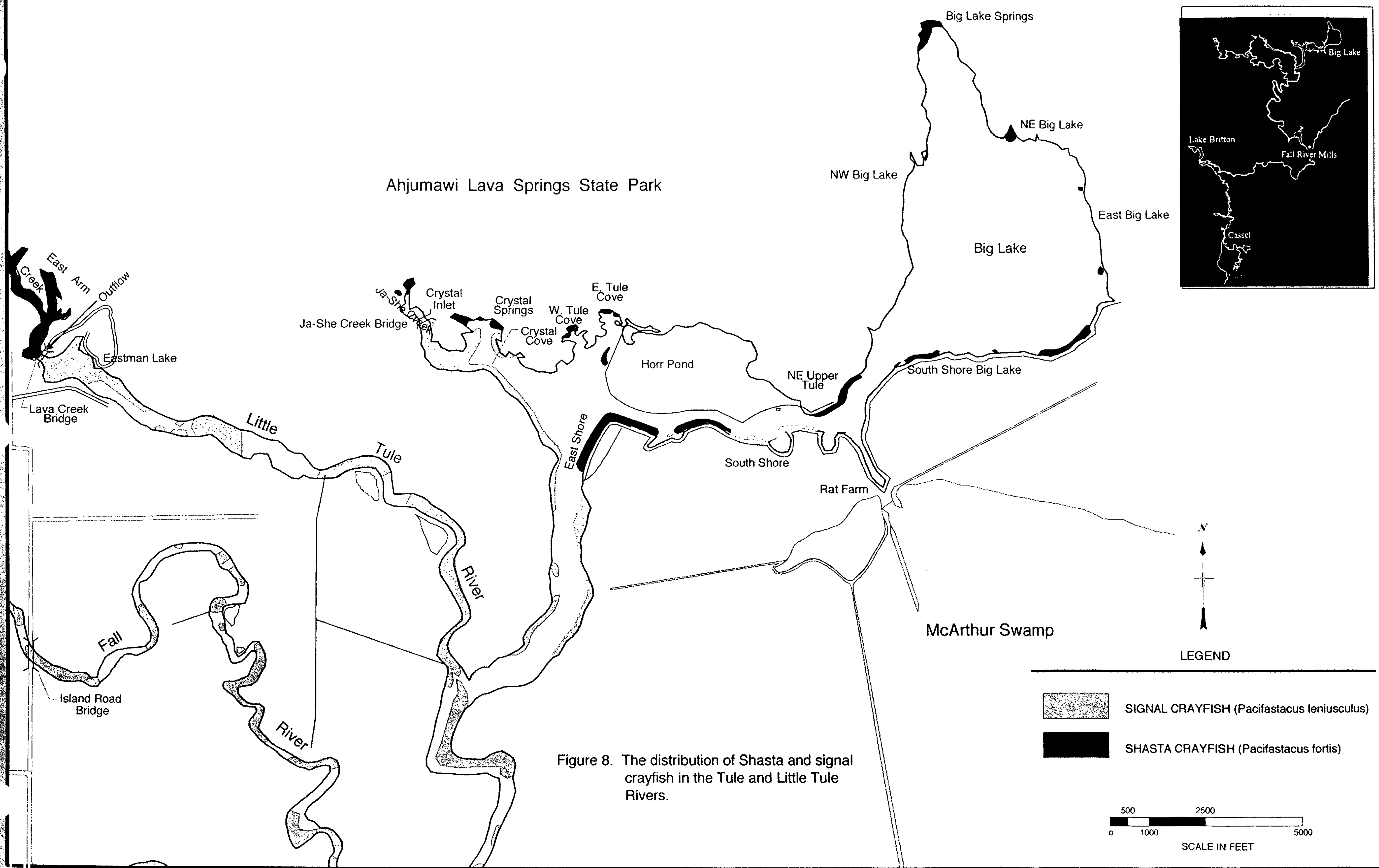

Figure 8. The distribution of Shasta and signal crayfish in the Tule and Little Tule Rivers.

feed into the Tule River east of the confluence of Ja-She Creek. Shasta crayfish in the upper Tule River were found in two distinctly different habitat types that had only lava substrate in common: the headwater spring areas and the manmade levees. The spring areas were characterized by constant temperature, flow, and clarity, and the lava substrate in the immediate spring areas was clean, with relatively little silt. The headwater spring areas of the upper Tule River are either part of, or border, Ahjumawi Lava Springs State Park. Shasta crayfish were also found in northeast Big Lake and northwest Big Lake bordering Ahjumawi Lava Springs State Park. Although these areas do not seem to be spring-fed, there is accessible lava substrate for the crayfish. These areas may have been associated with springs that were not flowing at the time of the surveys. A few Shasta crayfish have also been observed under the cobbles and large boulders along the east shore of Big Lake. Shasta crayfish on the south shore of Big Lake and the shores of the upper Tule River were associated with the levee system built at the turn of the century; most were found under lava rocks imported in the 1930's to help maintain and reinforce the levees. Shasta crayfish were found on the maintained levees along PG&E's McArthur Swamp and on the old levees bordering Ahjumawi Lava Springs State Park land, on the south shore of Big Lake, and along the north shore of the upper Tule River (Figure 8).

Fall River, Fall River Mills (Fall River Pond) Population. Although Shasta crayfish survived the diversion of the Fall River in 1922 and the construction of the Pit 1 Forebay in 1945, the species probably no longer exists at this location (Figure 7). Since the diversion, habitat for Shasta crayfish has probably been marginal. Fall River Pond is almost stagnant, generally eutrophic, with large seasonal fluctuations in water temperature (5–25 degrees Celsius [41–77 degrees Fahrenheit]), an overabundance of aquatic vegetation, and large daily fluctuations in dissolved oxygen. There is an abundant population of nonnative fish, including largemouth bass, green sunfish, and bluegill. Largemouth bass and green sunfish, both known crayfish predators, may have been introduced sometime between 1974 and 1978 (R. Daniels, unpubl. data 1974 and 1978; Eng and Daniels 1982).

The last detections at this location were of one live Shasta crayfish in 1974 (R. Daniels, unpubl. data 1974) and one dead one in 1978 (R. Daniels, unpubl. data 1978). No Shasta crayfish were found during surveys between 1990 and 1995 (Ellis and Hesseldenz 1993, Ellis 1996c). Both species of nonnative crayfish, signal and virile crayfish, are now found in Fall River Pond.

Pit River Population. Shasta crayfish probably were once present in areas of suitable habitat throughout the Pit River between Fall River and Hat Creek, an area fed by numerous springs and a large, spring-fed tributary, Sucker Springs Creek. Although disturbance and destruction of habitat and the invasion of nonnative species probably have reduced the suitability of much of this habitat, Shasta crayfish have been found in three locations in the mainstem Pit River (two upstream and one downstream of the Pit 1 Powerhouse) and in Sucker Springs Creek (downstream of the Pit 1 Powerhouse) (Figure 5).

The only historical records of Shasta crayfish in the mainstem Pit River were from the Pit River sand pits in 1978 (R. Daniels, unpubl. data) and at the outflow of a spring in the Pit River canyon in 1980 (L. Eng, unpubl. data). Daniels (unpubl. data) found eight Shasta crayfish, as well as virile crayfish, in the mainstem Pit River near the sand pits below the State Highway 299 Bridge on three dates in 1978; only signal crayfish were found in this area in a 1995 survey (Ellis 1996a). One dead juvenile male Shasta crayfish was found near a small spring upstream of the Pit 1 Powerhouse in 1980 (M. Rode, pers. comm. 1995). Although Eng suggested that this crayfish might have been from Sucker Springs (Eng and Daniels 1982), it is unlikely that this crayfish traveled almost 2.5 kilometers (1.5 miles) upstream through almost 2-percent-gradient rapids. In August 1995, one dead juvenile male Shasta crayfish was found under a cobble in the outflow area of the spring (Ellis 1996a). In addition, both signal and virile crayfish were found (Ellis 1996a). In 1995, four Shasta crayfish were found in slow water immediately upstream of the Pit River Falls (Ellis 1996a). Virile crayfish were fairly numerous in the area as well (Ellis 1996a).

Downstream from the Pit 1 Powerhouse, Sucker Springs Creek has a population of Shasta crayfish that has been isolated from the Fall River and Hat Creek populations since at least 1922 and probably represents a unique gene pool (Figure 5). Although Shasta crayfish have been found in the three downstream ponds (Ponds 3, 4, and 5) of the old California Department of Fish and Game Fish Hatchery, the current distribution of Shasta crayfish is mostly restricted to the spring area in Pond 3 (Ellis 1996b).

Hat Creek, Cassel Population. Hydroelectric development of the area has changed lower Hat Creek downstream of the town of Cassel. Crystal Lake, a spring-fed tributary near Cassel, however, remains mostly unmodified and now supports a Shasta crayfish population invaded by signal crayfish. Hat Creek below the outflow from Crystal Lake has since been impounded to form Baum Lake. The occasional Shasta crayfish found in Baum Lake below the outflow from Crystal Lake are probably wash-downs from Crystal Lake (Ellis 1994a). The Shasta crayfish in Baum Lake are probably not a self-sustaining subpopulation. Signal crayfish are very abundant near the inflow from Crystal Lake and common throughout the rest of Baum Lake (Ellis 1994a).

Rock Creek is a natural spring-fed creek, 1.4 kilometers (0.9 mile) long, that flows into Baum Lake approximately 30.5 meters (100 feet) downstream from the Hat 1 Powerhouse (Figure 5). Rock Creek is fed by water from Rock Spring and two spring-fed ponds, Rock Pond and Castro's Pond, near the Cassel-Fall River Road. Rock Creek was once a major spawning ground for brown trout, and Shasta crayfish were once common (L. Kerns, pers. comm. 1997, 1998). The population of Shasta crayfish in Rock Creek has been extirpated as a result of chemical treatments and water diversion for the Crystal Lake Fish Hatchery.

Rising River Population. The Rising River subdrainage is the largest contributor of water to Hat Creek. The springs that form Rising River and Rising River Lake are fed by snow melt from Lassen Peak. Although most of the spring areas in Rising River and Rising River Lake (Figure 5) appear to have good habitat with an abundance of lava substrate for Shasta crayfish, no Shasta crayfish were found associated with any of the springs in the Rising River subdrainage (Ellis 1995). The main Shasta crayfish population is in the outflow channel of Rising River Lake. This population was first discovered in 1978 and is the largest population in the Rising River subdrainage. During 1994 surveys, two new locations of Shasta crayfish, both associated with bridge sites, were found in the mainstem of the Rising River upstream from the Rising River Lake outflow channel (Ellis 1995).

G. Reasons for Decline and Current Threats

Although settlers of European descent did not come to the Pit River drainage until the mid-1800s, human activities in the area since that time have resulted in habitat loss and fragmentation. The potential for hydroelectric power from the Pit River drainage was first noted in 1875 (Scupman 1875). The water power potential of the Fall River was the major reason the town of Fall River Mills was founded. Development of the Fall River and Hat Creek Valleys for hydroelectric production began in 1920. Major land reclamation and water diversion projects for agriculture and cattle grazing began even earlier in the Fall River Valley. These activities would have further divided the population of Shasta crayfish into isolated pockets. The introduction of nonnative species of fish and crayfish into the drainage has also had a significant negative impact on Shasta crayfish. Many species of fish introduced into the area are known to prey on crayfish (Table 1). The introduced crayfish can be predators and competitors of the Shasta crayfish. In addition, natural disturbances resulting from the eruptions of Lassen Peak, floods, and drought have likely had a significant negative impact on Shasta crayfish.

Hydroelectric Development

Hydroelectric development, including the operation of four powerhouses in the midsections of the Pit River, represented one of the first broad-scale disturbances to the Shasta crayfish population. The range of Shasta crayfish and other aquatic species was divided into at least five regions by 1922 (see "Current Distribution and Population Status") due to habitat alterations, such as excavations, river impoundments, water diversions, inundations, and changes and reductions of flows. Some of the habitat alterations decreased the amount of available lava substrate.

Some secondary effects resulting from hydroelectric operations and management in the area include increased siltation and water temperature and decreased dissolved oxygen content in impounded sections. The Pit 1 Project impounded and/or dewatered regions where Shasta crayfish were found in the Fall River at Fall River Mills (type locality; see "Taxonomy"). Downstream from the Pit 1 Powerhouse, the Pit River has daily fluctuations in flow that can result in over a meter (3-foot) difference in the height of water in some areas and dewatering of the margins. These daily fluctuations create a freshwater "intertidal" region; few organisms are adapted to take advantage of the changing habitat. The Pit River upstream of the Pit 1 Powerhouse has a reduced flow.

Fishing and Fisheries Management

Six major activities associated with fisheries and fisheries management have affected Shasta crayfish: (1) the introduction of nonnative crayfish species; (2) the introduction of nonnative game fish species to provide sport fishing, with or without the sanction of California Department of Fish and Game and other agencies; (3) the introduction of potential crayfish pathogens by introduced species; (4) the management of hatcheries and hatchery trout; (5) the restoration and improvement of wild trout habitat; and (6) crayfishing. These activities have contributed to the observed decrease in the distribution and abundance of Shasta crayfish.

Nonnative Crayfish Introductions. Within the last two decades, two species of nonnative crayfish have been introduced into the midsections of the Pit River drainage. The virile crayfish was introduced in the 1960's, and the signal crayfish was introduced in the 1970's. The introduction of both species probably resulted from angling and the use of crayfish as bait (Eng and Daniels 1982). Although the first nonnative crayfish to be introduced into the area (Bouchard 1977a), virile crayfish have since been replaced throughout most of their range by signal crayfish. The signal crayfish has rapidly expanded its range throughout most of the Pit River drainage and occurs with Shasta crayfish in at least a portion of five of the seven populations (Table 2). The rapid expansion of signal crayfish has been linked to the diminished distribution of Shasta crayfish within their range (Ellis 1996d). Virile crayfish are potential competitors of Shasta crayfish in the newly discovered subpopulation in the Pit River (Ellis 1996a) upstream of the Pit 1 Footbridge (Figure 5). Interactions between Shasta crayfish and virile crayfish have not been studied.

Signal crayfish have all the characteristics of a classic invading species (Ehrlich 1989); they are larger, more aggressive, faster growing, earlier maturing, produce more offspring (Figure 9, Table 3, Abrahamsson 1971; Flint 1975; Goldman *et al.* 1975; Fürst 1977; Eng and Daniels 1982; M. Ellis, pers. observ.), and have a larger native range than Shasta crayfish. Signal crayfish also have a broader diet, greater physical tolerance (e.g., to water temperature and quality), and a higher daytime activity rate than Shasta crayfish (Ellis and Hesseldenz 1993). In contrast, Shasta crayfish are slower growing, with a long generation time, a smaller native range, a more restricted diet, a narrower tolerance range of physical conditions, and a smaller body size at all ages than signal crayfish (Table 3, Figure 9; Daniels 1980; Eng and Daniels 1982; M. Ellis, pers. observ.).

Signal crayfish generally are twice the size of Shasta crayfish at each age class (Figure 9), primarily due to a faster growth rate that gives signal crayfish a competitive advantage over Shasta crayfish of the same age. Additionally, signal crayfish become free-living days, weeks, or even months before Shasta crayfish (M. Ellis, pers. observ.). Signal and Shasta crayfish populations use the same

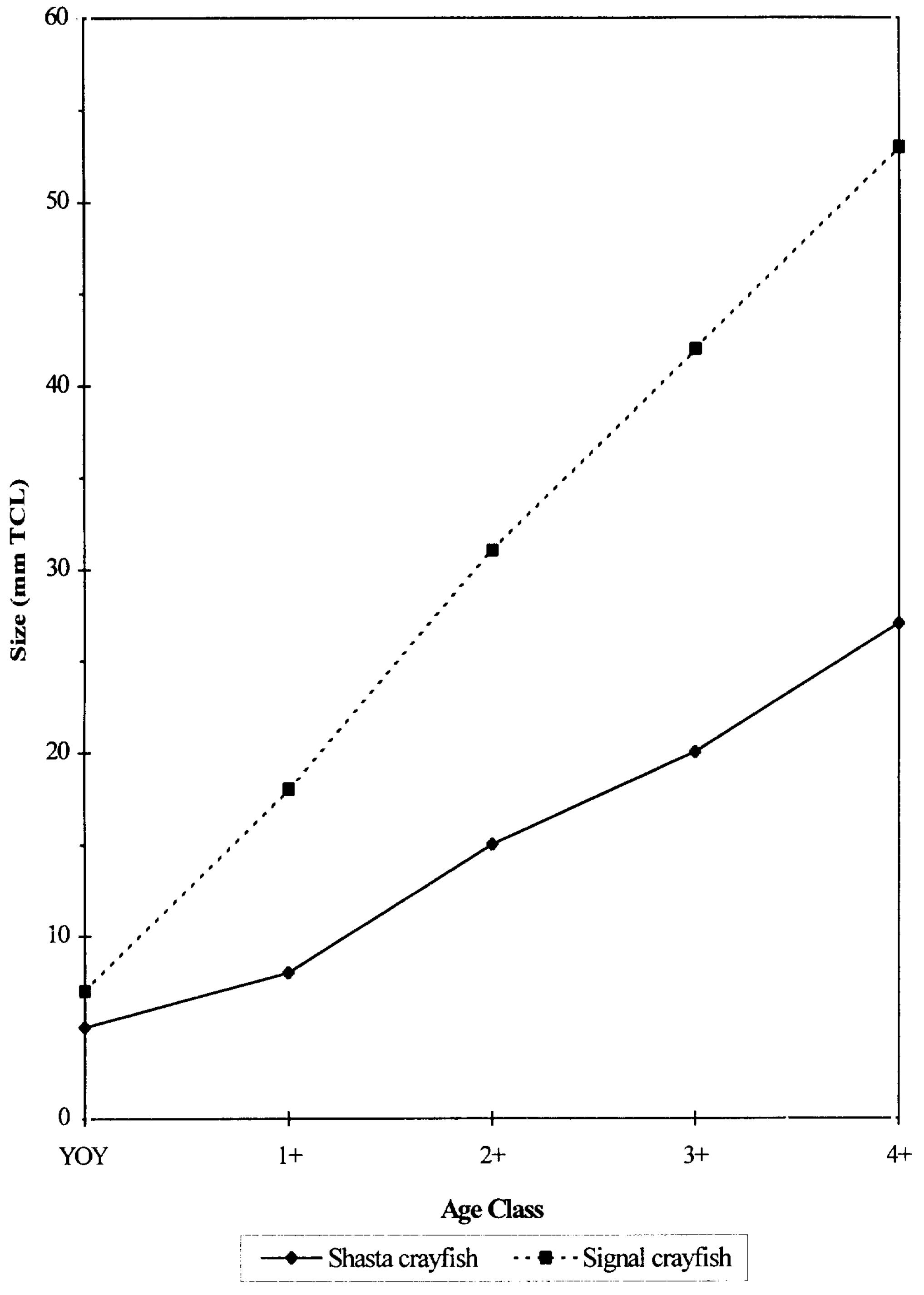

Figure 9. Ontogenetic (developmental) changes in body size of Shasta crayfish and signal crayfish in the midsections of the Pit River drainage in June (from Ellis 1991b).

Table 3. A summary and comparison of the life history traits of Shasta crayfish and signal crayfish in the midsections of the Pit River drainage.

Life History Trait	Shasta crayfish	Signal crayfish
Maximum Size [1]	58.70 mm (2.35 in)	74.65 mm (3.0 in)
Mean Size	26 mm (1.04 in)	28–54 mm (1.12–2.16 in)
	Sexual Maturity	
Female Age	5th year	2nd–3rd year
Female Size	27 mm (1.08 in)	36 mm (1.44 in)[2]
Male Age	5th year	2nd–3rd year[3]
Male Size	—	36 mm (1.44 in)[2]
Reproduction	one brood/season	one brood/season
Mating Season	late Sept/Oct	late Sept/Oct
Spawning	Oct/Nov	Oct/Nov
Number of Eggs	10–70 eggs/female	20–200 eggs/female
Egg Diameter	3.1–3.45 mm (0.12–0.14 in) Average = 3.3 mm (0.13 in)	2.3–3.0 mm (0.09–0.12 in)
Egg Hatching	late May/early July	May
First Instar	attached, 4–5 mm (0.16-0.2 in)	attached
Second Instar	clinging with claws 5–7 mm (0.20–0.28 in) late June	clinging with claws May/early June
Third Instar	free-living 5–7 mm (0.20–0.28 in) mid-late July	free-living 7–9 mm (0.28–0.36 in) early June
Young Of the Year (YOY)	7–8 mm (0.28–0.32 in)	13–16 mm (0.52–0.64 in)
End of Season	October	October
	Size Classes	
0+	5–8 mm (0.20–0.32 in)	7–17 mm (0.28 –0.68 in)
1+	8–14 mm (0.32–0.56 in)	18–30 mm (0.72– 1.2 in)
2+	15–19 mm (0.60–0.76 in)	31–41 mm (1.24–1.64 in)
3+	20–26 mm (0.80–1.04 in)	42–52 mm (1.68–2.08 in)
4+	adult 27 mm (1.08 in)	53–64 mm (2.12–2.56 in)
Growth	1–3 mm (0.04–0.12 in)/molt	5–10 mm (0.20–0.40 in)/molt[2]

Source: adapted from Ellis and Hesseldenz (1993)

[1] All lengths reported as total carapace length (TCL) (1 millimeter [mm] = 0.04 inch [in])

[2] *Pacifastacus leniusculus* in Sacramento-San Joaquin Delta (McGriff 1983)

[3] *Pacifastacus leniusculus* in Berry Creek (Mason 1975)

rocks for refuge and eat some of the same foods (exploitative competition) (Ellis 1993b). Signal crayfish are aggressive and cannibalistic, and Shasta crayfish do not change their behavior to avoid signal crayfish (Ellis in prep., Ellis 1996d), making Shasta crayfish vulnerable to competition and predation.

There has been considerable concern about hybridization between Shasta and signal crayfish. There has been no evidence, however, of any hybrid offspring in any of the populations, including Crystal Lake, which was invaded by signal crayfish in 1978. The more aggressive signal crayfish males may mate with female Shasta crayfish where they occur together. The absence of hybrid individuals, however, would indicate that only nonviable eggs are produced from matings between the two species, which could effectively reduce the reproductive output of female Shasta crayfish to zero for the year (reproductive interference). This type of reproductive interference can be costly to Shasta crayfish because they are slow-growing, late-maturing, and have low fecundity (produce fewer offspring). Reproductive interference in conjunction with differences in aggression and susceptibility of young crayfish to predation were major factors in the replacement of one species by another species of crayfish (Butler and Stein 1985).

Nonnative Fish Introductions. The introduction of exotic species of fish and crayfish, which are potential predators, competitors, and sources of new diseases and pathogens, is one of the biggest threats to the continued existence of the Shasta crayfish. Many species of nonnative gamefish were intentionally introduced into the midsections of the Pit River drainage to provide sport fishing opportunities. Some of these introductions were without the sanction of California Department of Fish and Game and other agencies. Brown trout, largemouth bass, smallmouth bass, black crappie, green sunfish, black bullhead, brown bullhead, and channel catfish have all been introduced within the range of the Shasta crayfish and are all known to prey on crayfish (Crocker and Barr 1968, Taub 1972, Rickett 1974). Common carp, which have also been introduced in the area, eat invertebrates living on river and lake bottoms. In particular, largemouth and smallmouth bass and green sunfish are known to be voracious predators on crayfish.

Potential Crayfish Pathogens. There is always a danger that the introduction or invasion of a new species will be accompanied by the introduction of other organisms, such as pathogens, parasites, and commensals (an organism that may derive some benefit from living on another organism, but neither harms nor is parasitic on its host). The transfer of parasites and diseases with the introduction of exotic species can have catastrophic consequences, such as the crayfish plague in Europe. In this case, the introduced species was resistant to the pathogen it carried, so that only the native species was devastated (Unestam 1973, 1975, von Broembsen 1989). Organisms that are harmless to their host species in its natural environment may become aggressive in a new environment or when introduced to a new species (Unestam 1975, von Broembsen 1989). Almost half of the locations where Shasta crayfish are currently found also have signal crayfish (Lowery and Holdich 1988) (Tables 2 and 4), which carry many diseases and pathogens that are probably foreign to Shasta crayfish (Ellis 1994b).

Branchiobdellidan worms are segmented worms, or annelids (Phylum Annelida) that are commensal on crayfish and do not generally harm the crayfish host. The worms may be found on the claws or chelae, in or around the gill chambers, or on the mouthparts of signal crayfish. Only one species of this worm has been documented to be parasitic on crayfish (Grabda and Wierzbicka 1969).

Two branchiobdellidan species, *Magmatodrilus obscurus* and *Sathodrilus shastae* (Goodnight 1940, Holt 1967, 1981), are known only from Shasta crayfish (Ellis 1996d). The former species was generally present in all Shasta crayfish populations and abundant in many (Ellis 1996d). The latter species was only common on Shasta crayfish in the outflow channel of Rising River Lake, and three specimens were found on one Shasta crayfish in Crystal Lake (Ellis 1996d). Three branchiobdellidan species were found on signal crayfish within the range of Shasta crayfish: *Xironogiton victoriensis*, *Cambarincola gracilis*, and *Sathodrilus* *attenuatus*. The first two of these species were also found on Shasta crayfish (Crystal Lake, mainstem Fall River, Sucker Springs Creek, and Lava Creek), but *Xironogiton victoriensis,* the most abundant species found on signal crayfish, was found most often on both Shasta and signal crayfish where the two species occur together (Ellis 1996d). This species was found on Shasta crayfish in five of the six locations where they occurred with signal crayfish.

The introduction of new species of these worms to Shasta crayfish provides another potential source of pathogens and parasites (Hobbs *et al.* 1967), as branchiobdellidan worms show evidence of having parasites of their own and are intermediate hosts for the eggs and larvae of other parasitic worms (Unestam 1969, Brinkhurst and Gelder 1991). Signal crayfish in California also carry parasites that have never been documented in Shasta crayfish (McGriff and Modin 1983).

Signal crayfish also carry several diseases, including those resulting from fungal (crayfish plague), protozoan, bacterial, and viral agents. Signal crayfish both carry and are resistant to the fungus that causes crayfish plague (Unestam 1969). The resistance of Shasta crayfish to crayfish plague has never been tested. Recently, a new virus was discovered in signal crayfish (Hedrick 1995), but the effects on the host are unknown (Groff *et al.* 1993; R. Hedrick, pers. comm. 1994). The virus was found in signal crayfish from Crystal Lake in the Hat Creek drainage of northeastern California, but was not found in signal crayfish from Ja-She Creek (Fall River drainage). Additional research will investigate the potential relationship between the decline in Shasta crayfish with the recently reported viral infections in signal crayfish (Hedrick 1995).

Entocytherid ostracods, freshwater crustaceans (mussel or seed shrimp) that depend on their hosts as sites for reproduction and rearing of young (Young 1971), are commensals on crayfish. Peritrich ciliates (Phylum Ciliophora) are protozoans that are often found colonizing the external surface of both Shasta and signal crayfish giving the crayfish a "furry" appearance (M. Ellis, pers. observ.).

Diatoms (Division Chrysophyta) and blue-green algae (Division Cyanophyta) are common on the exterior surface of crayfish (Hobbs *et al.* 1967; Holt 1986; M. Ellis, pers. observ.).

Hatchery Management. Various activities associated with the management of California Department of Fish and Game's Pit River and Crystal Lake fish hatcheries have adversely affected Shasta crayfish. Many of these activities are related to eradicating the protozoan *Ceratomyxa shasta*, which is present throughout most of the midsections of the Pit River drainage. *Ceratomyxa,* a parasite that infects the organs of most salmonid fish, is present in the lower Hat Creek drainage, including Crystal Lake and Rising River, as well as the Fall River drainage and the mainstem Pit River. *Ceratomyxa* is fatal to most nonnative strains of rainbow trout (Schafer 1968). Because the native trout are resistant to the protozoan, *Ceratomyxa* has been beneficial in maintaining the genetic integrity of the native Pit River strain of rainbow trout.

Rotenone and chlorine were used to eradicate intermediate hosts for *Ceratomyxa* in Crystal Lake in 1949 (Schafer 1968) and 1963 (M. Berry, pers. comm. 1995) and in Rock Creek in 1963 (Schafer 1968). The chemical treatment of Crystal Lake most likely killed many Shasta crayfish; individuals located near the springs may have survived, however, due to the influx of fresh water.

In 1950, California Department of Fish and Game constructed a dam 0.7 kilometers (0.4 mile) below Rock Spring and diverted the majority of the 24-cfs flow from Rock Creek through a 1.0-kilometer (0.6-mile)-long aqueduct (culvert) to the Crystal Lake Fish Hatchery. Over 90 percent of the discharge of Rock Creek is diverted through the culvert to the hatchery. Approximately 2 cfs of the 24-cfs discharge of Rock Creek still flows in its channel into Baum Lake. California Department of Fish and Game also constructed a catchment device, approximately 100 meters (328 feet) upstream from Baum Lake, which funneled water from Rock Creek into a 15-meter (49-foot)-long pipe and created a dry section of channel that is a barrier to fish passage. The chemical treatment and water diversion in Rock Creek extirpated Shasta crayfish at that location.

In 1964, California Department of Fish and Game leased property on Sucker Springs Creek from PG&E and began construction of the Pit River Fish Hatchery (Figure 1) within and adjacent to the Sucker Springs Creek channel. Heavy machinery was used in the stream channel to remove boulders, and Shasta crayfish were most likely crushed. Almost all of the preferred substrate for Shasta crayfish, lava cobble and boulders, was removed except around the area of the spring in Pond 3. River gravel was placed in the channel to facilitate hatchery operations. Heavy machinery, such as backhoes and tractors, were also used in the channel of Sucker Springs Creek for major maintenance of the hatchery ponds, such as after the flood of 1986 (L. Draper, pers. comm. 1995). Electroshocking was used in the ponds for trout management. Prolonged exposure to electroshocking can kill crayfish.

A dam across the Sucker Springs Creek upstream has caused siltation and sedimentation, eliminating any remaining Shasta crayfish habitat upstream. The dam has also improved habitat for snails (*Fluminicola* spp.) that are the intermediate host for the gill fluke, a common parasite that causes hatchery fish mortality.

Sucker Springs Creek was chemically treated on several occasions as either a treatment for, or prevention of, some trout diseases (West 1969). In 1994, 1,088 kilograms (2,400 pounds) of salt was added to the stream to exterminate snails (*Fluminicola* spp.) (R. Elliott, *in litt.* 1995). Salting is a nonspecific treatment that can be harmful or even lethal to Shasta crayfish. In addition, *Fluminicola* spp. is presumed to be a major food resource for Shasta crayfish.

Concrete weirs with four 2.4-meter (8-foot)- long wooden flashboards were used to divide the ponds and to increase water depth by backing water up in the channel until it flowed over the flashboards (West 1969). These weirs acted at least as partial barriers to the upstream migration of signal crayfish. During normal hatchery operations, the flashboards were never removed for longer than a few hours at the most. In 1996, the flashboards were removed for days to months to allow flushing of the ponds (M. Ellis, pers. observ.). The removal of the flashboards dewatered most of the lava cobble and boulder habitat for Shasta crayfish, forcing any surviving crayfish into the remaining shallow water in the middle of the channel with no protective cover. This action also allowed the invasion of signal crayfish into the pure (allopatric) Shasta crayfish population in Pond 3.

Wild Trout Management. To create additional spawning habitat for wild trout, PG&E added river gravel to the outflow area of Crystal Lake in 1965 (27 cubic meters [30 cubic yards]) and 1971 (82 cubic meters [90 cubic yards]). Heavy machinery was used to place gravel at the outflow area on top of the largest concentration of Shasta crayfish in Crystal Lake. Shasta crayfish would have been killed by the dumping of gravel and the heavy machinery. Cobble or boulders were placed on top of the gravel, thereby improving the habitat for the surviving Shasta crayfish.

As part of California Department of Fish and Game's wild trout program, a section of lower Hat Creek was chemically treated in 1968 to reduce the nongame fish population. This treatment killed nearly 6,349 kilograms (7 tons) of fish from the 5.6-kilometer (3.5-mile) project area and would also have killed any Shasta crayfish.

Crayfishing. There are no records of the extent or impacts of crayfishing that occurred either historically from the Pit River Indians and early settlers or in more recent times. In 1981, California Department of Fish and Game closed the midsections of the Pit River to crayfishing and the use of crayfish as bait in an attempt to protect the Shasta crayfish. Changes to the sport fishing regulations in

1994 and 1998 now allow crayfishing in most of the drainage where the introduced species are abundant. It is still illegal to use crayfish as bait in the Pit River and all tributaries between the Pit 3 Dam (Lake Britton) and the Fall River-Cassel Road Bridge at Fall River Mills, California, including Hat Creek and the Fall River and their tributaries (Figure 5). Other activities related to fishing and fisheries management mentioned above have had a greater effect on Shasta crayfish than crayfishing.

Land Reclamation

As early as 1903, the McArthur family of Fall River Valley began construction of approximately 20 kilometers (12 miles) of levees to reclaim 18 square kilometers (7 square miles) of marshland for agriculture and cattle grazing. These levees confine Big Lake, Tule River, and Little Tule River in their present channels. The effect of this land reclamation project on Shasta crayfish has been mixed. The lava rock imported to reinforce the levees created additional habitat for Shasta crayfish. The dredging generally used to build and maintain the levees and the cattle grazing on the reclaimed swamp land, however, have resulted in the degradation or loss of Shasta crayfish habitat through increased siltation, loss of riparian habitat, bank destabilization, and eutrophication of the system.

Shasta crayfish were first noted on the levees along the south shore of Big Lake in 1978 (R. Daniels, unpubl. data; Eng and Daniels 1982). During surveys conducted for PG&E in 1991 and 1992, Shasta crayfish were found under the lava rocks and boulders on the abandoned levee separating Horr Pond from Tule River at the boundary of Ahjumawi Lava Springs State Park, as well as the south shore of Big Lake (Ellis 1991a, 1993a, Ellis and Hesseldenz 1993). Shasta crayfish were also found on the levees along the upper Tule River, even though most of the lava rocks in this area have been buried or embedded by later dredging. Shasta crayfish along the south shore of the upper Tule River showed remarkable flexibility in their use of habitat by using burrows, wood, and the few accessible lava rocks as refugia.

Sedimentation

Sedimentation in the midsections of the Pit River drainage has been caused by a combination of activities including (1) channelization, (2) dredging, (3) logging, (4) forest fires, (5) culverts and bridges, (6) agriculture, (7) grazing, and (8) muskrat activity.

Channelization. With its drainage area of 217 square kilometers (84 square miles), Bear Creek is the only major sediment source in the Fall River system. Prior to its channelization, circa 1960, Bear Creek meandered gradually through the meadow at the lower end of its watershed until it flowed into Mallard Creek (Figure 4). The sinuous channel and broad floodplain moderated the impacts of high-water flows and allowed the meadow to accumulate and store much of the sediment brought down from the upper watershed.

Channelization of Bear Creek in the lower meadow changed the interaction between Bear Creek and its floodplain. As a result of channelization, the meadow became an active source of sediment as Bear Creek cut down through its bed and banks (R. Poore, unpubl. data). The floodplain has been largely abandoned, and the sedimentation rate and amount of sediment deposited into the Fall River has been greatly accelerated.

The movement of a large quantity of sediment (gravel, sand, and silt) from the Bear Creek watershed that resulted from high flows in Bear Creek, particularly in 1986, continues to impact the upper Fall River (Ellis and Hesseldenz 1993). Larger sediment, such as Bear Creek gravel, has been deposited in the higher gradient section between the mouth of Bear Creek and the Navigation Limit. Although it provides substantial trout and sucker spawning habitat, Bear Creek gravel has buried crayfish and sculpin habitat from the mouth of Bear Creek to the Navigation Limit (M. Ellis, pers. observ.). Sand and silt from Bear Creek is transported further downstream and impacts portions of the Fall River from the Navigation Limit to the Spring Creek Bridge (M. Ellis, pers. observ.). Patches of substrate clear of sand and silt do exist, however, in the upper Fall River downstream of the Navigation Limit, particularly near bends and channel constrictions (M. Ellis, pers. observ.). This demonstrates that the stream hydraulics are sufficient to move fine sediment through certain sections of the Fall River. In these areas of clean substrate, aquatic vegetation appears to be recovering (M. Ellis, pers. observ.).

The movement of sediment from Bear Creek has not been brought under control and continues to pose a threat to the mainstem Fall River. Given the low gradient of the mainstem Fall River, it will be many years, if ever, before Bear Creek sediments already in the river are completely flushed through the system. Shasta crayfish were probably once found throughout the upper Fall River wherever lava substrate was present. Bear Creek sediments may have buried former Shasta crayfish subpopulations and habitat in the upper Fall River. The two locations in the mainstem Fall River where Shasta crayfish were found in 1990–1993 are in serious danger of destruction. These upper Fall River subpopulations face continued and compounded threats because of mobile sediments and crowding by signal crayfish into these "islands" of higher quality substrate preferred by both species.

The section of Hat Creek upstream from the confluence with Rising River was channelized in the 1950's by the Army Corps of Engineers in a joint venture with private property owners along upper Hat Creek. The Army Corps of Engineers undertook the project because farmers and ranchers in the upper watershed were complaining that sediment was inundating their water diversions after the Hat Creek mudflow of 1915. Before channelization, this 4.8-kilometer (3-mile) section of Hat Creek had multiple channels that allowed sediment to be deposited on the creek's floodplain. Channelization increased the rate of sediment movement out of the upper drainage and deposited the sediment in lower Hat Creek. The sedimentation of lower Hat Creek covered lava gravel, cobbles, and boulders with fine sediment. The section of Hat Creek between the confluence of Rising River and the town of Cassel changed dramatically as the riffle filled in and the section immediately above it became a braided channel and lagoon (L. Kerns, pers. comm. 1997). The crayfish, bivalves, fish, and river otters all disappeared from the lower section after Hat Creek was channelized (L. Kerns, pers. comm. 1996).

Dredging. Beginning in 1903, approximately 19.3 kilometers (12 miles) of levees were constructed to hold Big Lake, Tule River, and Little Tule River in their present configuration. Damage to the levees by floods, wind and wave erosion, cattle grazing, and muskrat activity have required numerous repairs over the last 90 years. Between 1903 and the present, the levees were primarily repaired using material dredged from the bottom of the lake and rivers. During two periods, 1915–1940 and 1952–1962, there was no dredge in operation so repair and maintenance of the levees was accomplished using imported materials, including basalt lava cobble and boulder material.

Dredging operations can bury benthic organisms, particularly species with lower mobility. If material is deposited on the water side of the levees, lava substrate can be buried. A decrease in the amount of basalt lava substrate, especially where it is already limited such as the south shore of the Tule River, results in a significant loss of habitat for Shasta crayfish and other species that depend on that substrate. Dredging operations also increase the amount of suspended particulates in the water, which increases turbidity and sedimentation in the vicinity of the dredging operations and downstream.

Logging. Some forest management practices in the Bear Creek watershed have contributed sediment to Bear Creek. Bear Creek is the primary source of surface runoff into the Fall River, even though it is intermittent and seasonal in parts of its lower watershed. Bear Creek has contributed substantial sediment to the upper Fall River in recent decades. Although most of the watershed has been well-managed, past and present timber harvest practices, particularly in areas with steeper slopes, have contributed and continue to have the potential to contribute sediment to Bear Creek. Other activities associated with timber harvesting, such as stream crossings and road construction and use, have also contributed sediment to Bear Creek.

Forest Fires. Forest fires, and any subsequent salvage logging operations, have the potential to contribute sediment into adjacent watercourses. Most of the Fall River and Hat Creek flow through nonforested valley floors where the risk of impacts from fires is minimal. The entire watershed of Bear Creek was originally forested, with the exception of a few meadows and lava flows (T. McCammon, pers. comm. 1998). In 1977, the Pondosa fire burned 9,531 hectares (23,446 acres) in the mid-watershed of Bear Creek downstream of Pondosa, California (California Department of Forestry, unpubl. data). Reforestation efforts in the Pondosa burn area have been successful, although some small-acreage areas have not yet recovered a forested canopy. Refer to the previous section on logging for the effects of logging and sedimentation in Bear Creek.

Culverts and Bridges. Road and railroad crossings over streams and rivers typically involve placing culverts or constructing bridges. These structures have the potential to significantly impact rates of erosion and local sediment transport and delivery. Culverts and bridges are usually too small to deal with extreme flood flow. When high floods occur, water may be backed up behind the structures creating head pressures (pressure created by the difference in the two elevations of water) and flow velocities outside of the design specifications of the structures. Under such conditions the structures may fail. Typically water backs up until it begins to flow over the top of the road or railroad; as it falls back into the stream channel, it begins to scour and undermine the road and the structures.

Even if the structures do not fail, increased scour due to increased head pressure can have negative impacts on the streambed and banks downstream of the structure. If a structure fails, the resultant flood wave can carry excessive loads of sediment and debris downstream to the next structure, creating a potential cascading effect of structures being overwhelmed and failing throughout the watershed.

The railroad culvert in the upper watershed of Bear Creek on the south fork has failed multiple times and has contributed sediment to Bear Creek. The repeated railroad crossing failures in 1986 and 1997 were caused by water impounded by undersized and presumably blocked culverts during flood events. When the railroad crossing eventually failed, the release of the impounded water scoured the streambed and banks downstream. During 1997, a culvert became blocked on the south fork of Bear Creek at the State Highway 89 crossing, probably due to the failure of the railroad crossing upstream. The blocked culvert created a lake on the upstream side of the culvert. When the culvert cleared, the released flow resulted in substantial scouring downstream of the culvert.

Agriculture. The primary land use in the Fall River and Hat Creek Valleys is pasture. Land is also cultivated for potatoes, grains, and, most recently, wild rice. Wild rice ponds could be a source of nutrients, pesticides, and sediment for the river contributing to a decline in water quality that would negatively impact the abundance and diversity of aquatic insects and other invertebrates, as well as the fishery. The effects of wild rice farming have not been studied since 1984, when a study determined that rice farming had either unmeasurable or insignificant effects on water quality in the Fall River (Lewis 1985)

Grazing. The impact of livestock grazing in the riparian zone along the rivers and lakes can be seen throughout the midsections of the Pit River drainage. During the last 5 years, however, significant progress has been made in fencing livestock out of the riparian zone. PG&E fenced the entire McArthur Swamp area along the upper Tule River and Big Lake. Many landowners in the upper Fall River have either fenced their property or are currently working to do so. Cattle grazing in the meadows of Bear Creek has also had a negative impact on Bear Creek. Two of these meadows, however, have been fenced in the last few years. The riparian zone of one of these meadows (Long Ranch) is already beginning to heal (M. Ellis, pers. observ.).

When cattle and other livestock graze riparian vegetation, the banks of the stream channel can become more vulnerable to erosion and mechanical breakdown. In addition, livestock can physically break down streambanks. Erosion and breakdown of the banks results in over-widening of the channel, which decreases the ability of the stream to transport sediment. In addition to increased sedimentation, bank and riparian zone destruction, and over-widened stream channels, grazing can also result in nutrient loading. All of these processes contribute to the loss of lava substrate and habitat.

Muskrat Activity. Muskrats are not native to the midsections of the Pit River drainage or to most of California (Storer 1938). Muskrats were introduced into the Fall River drainage around 1930 from the Mount Shasta Fur Farms next to Big Lake (Storer 1938). By 1938, muskrats were found throughout the Fall River and lower Hat Creek drainages (Storer 1938). The burrowing of muskrats, in conjunction with livestock grazing, causes bank erosion and breakdown, which contributes sediment to waterways. Muskrats also prey on crayfish. Muskrat activity along the levees of upper Tule River has a negative impact on Shasta crayfish. The control and/or eradication of muskrat populations in the watershed would be beneficial to Shasta crayfish.

Geothermal Development

Preliminary data indicate that the Medicine Lake Highlands is the recharge area (source of water) for the Fall River springs (Rose *et al.* 1996). Since 1981, the

Bureau of Land Management has issued numerous leases for the purpose of exploring and developing a geothermal resource within the Medicine Lake Highlands area. In the last 2 years, geothermal development of the Medicine Lake Highlands for power generation has been proposed for two areas: Fourmile Hill Power Plant in 1995 and Telephone Flat Power Plant in 1997. Another exploratory drilling project within the Glass Mountain Known Geothermal Resource Area was also proposed in 1995. Environmental assessments and Findings of No Significant Impact were prepared for both of the 1995 project proposals. The Alturus Resource Area of the Bureau of Land Management, U.S. Forest Service, Modoc National Forest, U.S. Department of Energy, Bonneville Power Administration, and Siskiyou County Air Pollution Control District are jointly preparing an Environmental Impact Statement/Environmental Impact Report for the proposed Telephone Flat Geothermal Development Project.

If geothermal development or exploration of Medicine Lake Highlands contaminates the fresh water that recharges the Fall River springs system, wide-scale extirpation of most Shasta crayfish populations could result. Because the majority of both populations and individuals of Shasta crayfish are found in the Fall River drainage, the extirpation of the Fall River populations of Shasta crayfish would likely lead to the species' extinction.

The interconnection between the shallow fresh water that recharges the Fall River springs system and the deeper geothermal groundwater should be determined before further exploration or development of the Medicine Lake Highlands is done. Perturbations to one of these groundwater systems may result in disturbance of the other (R. Poore *et al.*, *in litt.* 1997). The recharge areas and their degree of interconnectivity with the springs in the midsections of the Pit River drainage should be determined. These recharge areas should be protected from all potential disturbances, such as geothermal development and water diversions.

Investigations using isotope hydrology to determine the origin and subsurface paths of groundwater have been conducted for Hat Creek basin (Rose *et al.* 1996) and are proposed for Fall River basin (Davisson *et al.* 1997). Isotopes (atoms of the same element but with slightly different masses) present in water can be highly diagnostic groundwater tracers, providing specific information regarding the water's origin.

Further Water Resource Development

Any proposals for development of the water resources in the area, including the recharge area, that entail diverting, removing, impounding, or otherwise impacting the discharge, temperature, chemistry, or clarity of the water should be thoroughly investigated prior to development. Particular attention should be directed at any developments that would directly impact the discharge, temperature, chemistry, or clarity of the springs or water in the midsections of the Pit River and/or Shasta crayfish habitat. Restrictions on development may be necessary.

Velocity Barriers

Road construction and associated bridges and culverts at stream crossings have created at least partial velocity barriers at Spring, Lava, and Ja-She Creeks, which probably acted to further subdivide Shasta crayfish within the Fall River drainage. These barriers have served a more beneficial role in the last two decades helping to slow the expansion of signal crayfish into Shasta crayfish habitat.

Natural Disturbances

Hat Creek Mudflow of 1915. On May 19, 1915, lava flowed over the southwest and northeast sides of the crater on Lassen Peak. The northeast flow melted a deep snowbank creating a flood of water, condensed steam, mud, and ash that plunged down the mountainside through Hat Creek and its tributary Lost Creek. The mudflow swept down approximately 30 kilometers (19 miles) of Hat Creek, cutting a 400-meter (0.25-mile)-wide path through forests and ripping bark off trees almost 6 meters (20 feet) above the ground. The wall of mud demolished cabins and homesteads, crushed trees, and deposited up to 6 meters (20 feet) of mud and debris on fertile meadows (U.S. National Park Service 1974, Schulz 1990).

Although most of the mud was deposited in the upper sections of the Hat Creek drainage, the sheer volume of water and sediment that reached lower Hat Creek would have resulted in considerable scouring and deposition. According to California Department of Fish and Game Reports, all trout in the mainstem Hat Creek were either washed out or killed by the mudflow and floods associated with the early eruptions of Lassen Peak (Merrill 1916, Bryant 1918, California Department of Fish and Game 1920). Shasta crayfish in mainstem Hat Creek would also have been either buried in mud or swept downstream by the tremendous mudflow. This mudflow isolated Shasta crayfish in the tributaries of Hat Creek (Rising River, Rising River Lake, Rock Creek, and Crystal Lake).

High Flows, Floods, and Drought. The 100-year flood of 1986 caused the Pit River to overflow its banks, scouring its channel as well as some of the spring-fed tributaries, including Sucker Springs Creek. Although once commonly observed, Shasta crayfish became a rare sight after the flood (L. Draper, pers. comm. 1995). Since the majority of remaining Shasta crayfish live in the spring-fed headwaters of the drainage, scouring from floods and high-water events is not a serious threat. Shasta crayfish in Sucker Springs Creek, however, have experienced several high-water events from the nearby Pit River, such as the high flows (up to 15,000 cfs) in the Pit River canyon during the spring of 1995 (U.S. Geological Survey, unpubl. data). Shasta crayfish survived high flows in the mainstem Pit River in 1964, 1986, 1993, 1995, and 1996; however, the impacts of high flows on Shasta crayfish in the Pit River are unknown.

In 1986, high flows in Bear Creek resulted in the flooding of areas in the upper Fall River. The resulting movement of large amounts of sediment from the Bear Creek watershed continues to impact the upper Fall River. High flows since 1986 have cleared sediment from portions of the upper channel and inundated portions of the channel downstream from the initial plug of sediment.

A shortage of water for extended periods of time has been a common problem in the last 20 years. Although it is unclear whether the 7-year (1987–1993) drought affected Shasta crayfish populations, the volume of water in the rivers was substantially lower than normal, and several springs were no longer flowing during the last year of the drought. Although the base flow in the Fall River is generally around 1,200–1,400 cfs, it fell to only 675 cfs before the drought ended (Rose *et al.* 1996). The rate of siltation and the resultant loss of habitat would have increased throughout the Pit River drainage during this period because flushing in the spring areas was reduced when the flows decreased. Lava substrate in areas where the springs have stopped flowing rapidly becomes silted over without the flushing provided by the spring flow.

Habitat Changes and Threats To Individual Populations

Table 2 details current threats to individual populations or subpopulations, in addition to providing information on the status of Shasta crayfish at each site and land ownership and suggesting habitat restoration actions.

Upper Fall River. The spring areas in the upper Fall River are generally pristine with an abundance of good-to-excellent Shasta crayfish habitat. In many cases, such as Thousand Springs, the potential Shasta crayfish habitat is much more extensive than the habitat actually used.

There are two major threats to Shasta crayfish in the upper Fall River drainage: loss of Shasta crayfish and their habitat due to sedimentation from Bear Creek and the movement of signal crayfish up the Fall River. Sedimentation from Bear Creek (previously discussed under "Reasons for Decline and Current Threats") covers lava-cobble-on-lava-gravel substrate characteristic of the best habitat throughout the upper Fall River drainage, which includes the two mainstem Fall River subpopulations of Shasta crayfish. Bear Creek sediment has been deposited in a kilometer (0.62 mile) of good-to-excellent Shasta crayfish habitat between Thousand Springs and Rainbow Spring (Figure 4). As a result, the two subpopulations separated by this section of the river probably have had restricted contact, which in turn reduces the exchange of genetic material (gene flow) between them. Shasta crayfish are prone to being entombed by highly mobile sediments. Downstream from Bear Creek, Shasta crayfish were only found where there was no Bear Creek gravel, such as in the sand springs area.

The other major threat to the upper Fall River is the invasion of the introduced signal crayfish, which has already reached the outflow of Rainbow Spring. An old dam at the outflow of Rainbow Spring creates a barrier to keep signal crayfish from migrating into Rainbow Spring. There are no barriers to prevent signal crayfish from reaching Thousand Springs (although Bear Creek sediments may have slowed their progress somewhat).

Although there has been grazing on Thousand Springs in the past, all livestock has been restricted from the riparian zone for the past 7 years. Proper land management, including stream bank protection (i.e., cattle grazing/fencing issues, and maintaining a healthy riparian zone through timber management), remain important issues downstream from Thousand Springs and in the Bear Creek drainage.

In 1996, the Fall River Wild Trout Foundation (FRWTF) submitted a proposal to the Cantara Trustee Council for a pilot project to remove sediment in the Fall River (FRWTF 1996). Although the proposal was for a pilot project to suction dredge in the river (Phase I), Phase II of the interim measures listed in the proposal was to conduct a full-scale suction dredging operation of the 8-kilometer (5.5-mile) section of the Fall River between the Navigation Limits and Spring Creek Road Bridge (FRWTF 1996). The full-scale suction dredging operation of upper Fall River (Phase II) would remove approximately 182,800 cubic meters (200,000 cubic yards) of what they consider to be recent sediment deposited after the early 1980's (FRWTF 1996). Suction dredging a large section of river would constitute a large-scale perturbation to the aquatic animal and plant communities. Suction dredging would result in direct mortality of any benthic organisms, such as Shasta crayfish (Nelson *et al.* 1991, Waters 1995).

Spring Creek. The property along Spring Creek is leased as a working cattle ranch. The short-duration seasonal cattle grazing allowed in the riparian zone is restricted primarily to lava flow areas as compared to bank areas composed of organic material. There seems to be little damage to the stream banks. The habitat for Shasta crayfish in lower fish trap cove would be improved by additions of lava cobbles and boulders.

The Fall River flooded in early January 1997, and water backed up into Spring Creek. Subsequently, signal crayfish were found in upper Spring Creek after they apparently moved through the culverts at the Spring Creek Road crossing during the flood. A total of 4 adult and 20 young-of-the-year signal crayfish were removed during 2 surveys in the summer of 1997 (T. Healey, *in litt.* 1997; M. Ellis, unpubl. data). All signal crayfish were found in the pool immediately upstream from the culverts. No signal crayfish were found in either the lower fish trap cove or the section between the cove and the culvert pool on August 20, 1997 (M. Ellis, unpubl. data). The invasion of signal crayfish into upper Spring Creek is an immediate and serious threat to the two Shasta crayfish subpopulations in Spring Creek. All signal crayfish must be eradicated from upper Spring Creek before they invade the two Shasta crayfish subpopulations and before they have an opportunity to reproduce.

Lava Creek. Shasta crayfish are no longer found in either of the two ponds that were once part of the Lava Creek drainage. The Shasta crayfish population that Daniels found in the northern pond in 1978 was extirpated due to predation from introduced largemouth bass and siltation and nutrient loading resulting from hydrologic alterations, periodic drought conditions, human activities, and an abundance of waterfowl. Most of the lava substrate in both ponds has been covered with organic sediment and silt. Lava Creek has received sediment from the ponds, as well as from past agricultural activities that include an extensive pig farm on the fields adjacent to the outflow. Current land uses include haying and grazing of perennial grasses on laser-leveled fields, which are periodically flood-irrigated.

The principal current threat is the ongoing invasion of signal crayfish. Signal crayfish were first found in Lava Creek above the outflow in 1990, having migrated up from Eastman Lake. By 1993, signal crayfish were found throughout the section between the outflow and where the east and west arms come together (confluence). Both the number and distribution of signal crayfish in Lava Creek continue to increase. Signal crayfish will continue to invade further upstream into the east and west arms of Lava Creek. The upstream expansion of signal crayfish in Lava Creek has been coincident with a drastic decrease and disappearance of Shasta crayfish in the lower sections of Lava Creek.

Tule River. All of the lava gravel, cobble, and boulder material associated with the levees is assumed to have been imported for the repair and maintenance of the levee system. Until the recent exclusion of cattle, the combination of cattle grazing and wind caused extensive erosion on the levees. During the last century, this levee erosion, combined with dredging used to repair eroded levees, has produced a thick layer of silt that has buried much of the lava substrate. PG&E has recently fenced all of their levees along Big Lake and the Tule River so that cattle are excluded from the levees (see "Conservation Measures").

Water temperature in the river and lake along the levees is extremely variable seasonally, ranging from 3–23 degrees Celsius (37–73 degrees Fahrenheit) (PG&E, unpubl. data). There is little to no visible flow of water in the upper Tule River drainage, and it generally becomes very eutrophic during the summer.

California Department of Fish and Game has attempted to introduce brown trout, rainbow trout, white catfish, channel catfish, and brown bullhead into Big Lake, with somewhat limited success. Largemouth bass, known crayfish predators, were also introduced into Big Lake, however, and are thriving. Although the largemouth bass is a warm-water species, juveniles tend to use the spring areas as a refuge from larger fish predators, and in the winter adults take advantage of the relatively warm environment in the spring areas (D. Weidlein, pers. comm. 1996). The presence of largemouth bass in the spring areas may explain the low density of Shasta crayfish found in the springs of the upper Tule River drainage relative to other springs in the Fall River drainage. Current threats include the absence or shortage of lava substrate, dredging, and invasions by and interactions with signal crayfish and, potentially, with virile crayfish.

Fall River. The construction and operation of the Pit 1 Hydroelectric Project drastically altered the physical characteristics and hydrology of the Fall River through dredging and filling, flooding and impounding, and diversions and alterations of water flow. Available evidence indicates that when Rutter and Chamberlain collected Shasta crayfish in the Fall River at Fall River Mills in 1898, there was an abundance of clean lava substrate and rapidly flowing, well-oxygenated water that supported a healthy community of native species. By the time Daniels found Shasta crayfish in the impounded section of the Fall River at Fall River Mills (Fall River Pond) in 1974 and 1978, available lava substrate had been severely depleted, and the river was a stagnant pond with large diurnal fluctuations in oxygen. In addition, the native aquatic community has since been almost entirely replaced by nonnative species, including four species of sunfish and bass and two species of crayfish. Shasta crayfish are considered extirpated from this location, as none have been found in recent surveys (Ellis and Hesseldenz 1993, Ellis 1996c).

Pit River. Two major impacts to the Pit River include the 1922 diversion of the Fall River to the Pit 1 Powerhouse, which significantly reduced the flow of water through the Pit River canyon, and the construction and operations of the California Department of Fish and Game Pit River Hatchery, a small fish hatchery consisting of five fish ponds in the Sucker Springs Creek channel (see "Hatchery Management" under "Fishing and Fisheries Management").

In 1996, removal of flashboards between ponds at the Pit River Hatchery on Sucker Springs Creek severely impacted the Shasta crayfish subpopulation in Pond 3. This population almost certainly represented a genetically unique stock that had been isolated from other populations for a long time. Current threats to the Sucker Springs Creek population include further invasions by, and interactions with, signal crayfish and a shortage of lava cobble/boulder substrate. In April 1997, California Department of Fish and Game decided to close the fish hatchery in Sucker Springs because operation of the fish hatchery was determined to be incompatible with protecting the Shasta crayfish population. Restoration efforts are under way to return Sucker Springs to natural Shasta crayfish habitat and attempt to conserve the remainder of the population.

Although little is known about the mainstem Pit River subpopulation, current threats include further invasions by, and interactions with, both signal and virile crayfish and poor water quality.

Hat Creek, Cassel. When the Army Corps of Engineers channelized Hat Creek in the 1950's (L. Kerns, pers. comm. 1994), the downstream movement of sediment from the Hat Creek Mudflow of 1915 was greatly accelerated and continues to impact potential Shasta crayfish habitat. Shasta crayfish populations have been documented in the spring-fed lakes and rivers feeding into lower Hat

Creek, but not in mainstem Hat Creek itself since the mudflow. Habitat and hydrology have been impacted by the construction and operation of the Hat Creek Hydroelectric Project.

Several trout management and restoration techniques applied to the Hat Creek drainage since the 1940's were done without knowledge of either the presence of or the potential impacts on Shasta crayfish. Rotenone and liquid chlorine were used in both Crystal Lake and Rock Creek as part of an eradication program for the protozoan *Ceratomyxa* (Schafer 1968; M. Berry, pers. comm. 1995). Rotenone was also used to remove nongame fish as part of the wild trout program on Hat Creek. A toxicant such as rotenone is also toxic to invertebrates, such as crayfish.

After the addition of spawning gravel to the outflow of Crystal Lake in 1965 and 1971, Shasta crayfish were not found in the area until lava cobbles and boulders were unburied and relocated on top of the gravel in 1992–1993 (M. Ellis, pers. observ.). Signal crayfish invaded Crystal Lake in 1978 and by 1991 outnumbered Shasta crayfish seven to one (Erman *et al.* 1993). In 1993, Ellis estimated that the current size of the Shasta crayfish subpopulation at the outflow of Crystal Lake was less than 10 percent of the 2,000 to 3,000 individuals estimated in 1978 (Daniels 1978). Signal crayfish pose the major threat to Shasta crayfish in the outflow of Crystal Lake.

Crystal and Baum Lakes receive considerable fishing pressure, including crayfishing, and other disturbances from public use. According to L. Eng (unpubl. notes), crayfish at the outflow of Crystal Lake are particularly vulnerable to hand collecting. Bullfrogs and brown bullhead have been introduced to the lakes. Grazing, logging, and other disturbances have contributed to surface runoff, sedimentation, and eutrophication of the lakes. The lack of exclusion fencing allows cattle to graze in the riparian zone and wade into the lakes. There is evidence of bank erosion in parts of both lakes.

Rising River. Aerial photographs from 1957, 1964, 1973, and 1993 all show a white plume of fine sediment issuing from the springs in the middle arm at the west end of the headwater spring system (not Rising River Lake) and some in the headwater spring closest to the middle arm, but none coming from any of the other headwater springs. There have been no studies of the sediment in Rising River upstream of Hat Creek, so the ultimate source of this sediment and the rate at which it enters the river or travels downstream are unknown. There is some anecdotal evidence indicating that fine sediment in Rising River has increased in recent times.

Rising River and Rising River Lake were once the location of several working ranches. Although there are still livestock in areas, there is no grazing in the riparian zone. There is little evidence of bank erosion. In general, this area has been relatively undisturbed. Native beaver and introduced muskrats are both common.

The Rising River Shasta crayfish populations are currently free of signal crayfish. The potential invasion by signal crayfish is the principal current threat.

H. Conservation Measures

Regulatory Measures

The Shasta crayfish was listed as an endangered species by the California State Fish and Game Commission in 1988, thus offering protection from take, possession, or sale within the State of California. Other State regulations prohibit the take, possession, or use for bait of any crayfish species within the range of the Shasta crayfish. These regulations were enacted to protect the Shasta crayfish and prevent the accidental spread of exotic crayfish; however, enforcement is difficult because of the large size and remoteness of the area.

In an attempt to protect the Shasta crayfish, California Department of Fish and Game closed the midsections of the Pit River to crayfishing and the use of crayfish as bait in 1981. Areas where the introduced species are abundant will be open for crayfishing as of March 1998, including (1) the Fall River from Spring Creek Bridge to the confluence with the Pit River; (2) Eastman Lake and Little Tule River, exclusive of Lava Creek; (3) Hat Creek downstream from the confluence with Rising River to the confluence with the Pit River, exclusive of Crystal Lake; (4) the Pit River, exclusive of Sucker Springs Creek; and (5) Lake Britton.

Closures for the protection of Shasta crayfish still exist in the Fall River upstream of Spring Creek Bridge, Lava Creek, Tule River and all connected water upstream of Little Tule River, Sucker Springs Creek, Crystal Lake, Rising River, and Rising River Lake, which are closed to the take and possession of crayfish. It is still illegal to use crayfish as bait in the Pit River and all tributaries between the Pit 3 Dam (Lake Britton) and the Fall River-Cassel Road Bridge at Fall River Mills, California, including Hat Creek and the Fall River and their tributaries.

The Shasta crayfish was federally listed as an endangered species on September 30, 1988 (U.S. Fish and Wildlife Service 1988). Federal agencies are required to consult with the U.S. Fish and Wildlife Service under the provisions of section 7(a)(2) of the Endangered Species Act (Act) on any action that they fund, permit, or implement that may affect Shasta crayfish. The provisions of Section 9 also make it illegal to ship, sell, or offer for sale in interstate or foreign commerce any listed species, or part thereof, taken in violation of the Act. The U.S. Fish and Wildlife Service also enforces the provisions of section 9 of the Act, which make it illegal to harass, harm, pursue, hunt, shoot, wound, trap, capture, collect, or to attempt to engage in any such conduct. If a non-Federal action would result in take of Shasta crayfish, an incidental take permit, issued by the U.S. Fish and Wildlife Service under section 10(a)(1)(b) of the Act, would be required. Section 6 funding is provided to states for actions that will aid the recovery of listed species.

There are currently no formal consultations on file for the Shasta crayfish since 1988, when it was listed. The relicensing of PG&E's Pit 1 Hydroelectric Project on the Pit River in 1997–1998 will require the Federal Energy Regulatory Commission to formally consult with the Service to address the effects of the project on Shasta crayfish. The Hat Creek Hydroelectric Project will also be relicensed by 2000, and PG&E will be addressing the improvement of land use practices and protection zones around lakes.

The California Water Resources Control Board issues both waste discharge permits for liquid waste discharges and 401 Water Quality Certifications for discharges to navigable waters, which require a Federal permit or license. California Department of Fish and Game issues Stream and Lake Alteration Agreements under Sections 1600–1605 of the California Fish and Game Code for the alteration of any stream or water course depicted as a blue-line channel on U. S. Geological Survey (U.S.G.S.) topographic maps.

Fall River Sediment Study

The Fall River Resource Conservation District is a board of volunteer local landowners and resource users who serve as a liaison between local landowners and government agencies on resource conservation issues. The Fall River Resource Conservation District is partially funded through Shasta County taxes, and was awarded a $200,000 grant in conjunction with the State Water Resources Control Board's Clean Water Act (205j grant). Under the 205j grant, Fall River Resource Conservation District contracted with the environmental planning firm Tetra Tech, Inc. to conduct a study of the sedimentation of the upper Fall River and Bear Creek watershed and develop a restoration plan. This study will address the relative importance and contribution of logging, forest fires, and other potential sources of sediment to Bear Creek. As part of the study, the Natural Resource Conservation Service inventoried the active sediment sources in the Bear Creek watershed. This project will also include developing restoration and mitigation alternatives, identifying causes of erosion, developing a monitoring program, performing lab analyses of sediment, conducting fish counts, developing a quality assurance plan, and drafting a final restoration plan. The final report is scheduled to be completed May 1998. This project is being conducted in conjunction with other studies by the California Department of Water Resources, Natural Resources Conservation Service, California Department of Fish and Game, North State Resources, and the U.S. Department of Agriculture.

Timber harvesting groups should be encouraged to continue to improve, monitor, and reevaluate land management practices, to consider potential impacts on endangered species downstream, and to work in cooperation with groups such as the Fall River Resource Conservation District.

Bear Creek Restoration

A cooperative effort has been initiated between the property owner of Bear Creek meadow and a manager of much of the timber lands upstream to reduce and stabilize the sediment flux into Fall River from Bear Creek. Such measures have included exclusion of cattle from riparian areas and replanting of native willows adjacent to the creek. Studies on Bear Creek have determined that a current major sediment source is the degraded channel in Bear Creek meadow, rather than the upper watershed (R. Poore, unpubl. data). In consultation with experts in the field of fluvial geomorphology and hydrology and stream restoration (L. Leopold, pers. comm. 1994; D. Rosgen, pers. comm. 1994), a plan has been developed to stabilize the channel through the meadow (R. Poore, pers. comm. 1996). This plan was developed to meet three primary objectives: (1) to connect the channel with the floodplain, (2) to eliminate the meadow section as a major sediment source, and (3) to maintain the channel through the meadow.

The Natural Resources Conservation Service inventoried potential sediment and erosion sources in the Bear Creek watershed during 1997 as part of the Fall River Sediment Study.

Levee Management

PG&E began fencing the levees surrounding McArthur Swamp in Fall 1991. By the end of 1992, exclusion fences surrounded all of McArthur Swamp except for the Wildlife Habitat Improvement Area. Fencing in the Wildlife Habitat Improvement Area was completed in the Fall of 1995 (M. Drury, pers. comm. 1996). PG&E addresses habitat enhancement and alternatives to dredging in its current application for a section 404 permit from the Army Corps of Engineers for long-term levee maintenance along the upper Tule River.

Cattle that graze on McArthur Swamp are now excluded from the PG&E levees, Big Lake, and the Tule River. This will reduce the need for levee maintenance, improve bank condition and riparian vegetation, and help stop the degradation of existing Shasta crayfish habitat.

Although PG&E still uses dredging as the primary method of levee maintenance and repair, it constructed a road on the levee west of Rat Farm (Figure 8) and imported material that included lava cobbles and boulders to repair a major levee breach resulting from the January 1, 1997, high-water event. New potential Shasta crayfish habitat is created when these materials are imported to areas within the known distribution of the Shasta crayfish.

Pit River Fish Hatchery

Signal crayfish invaded the Sucker Springs Creek subpopulation of the Shasta crayfish when barriers between Ponds 3, 4, and 5 were removed for approximately one month in August 1996. In April 1997, California Department of Fish and Game decided to close the Pit River Fish Hatchery permanently. California Department of Fish and Game has been conducting surveys of Pond 3 and eradicating any signal crayfish that are found. California Department of Fish and Game and the U.S. Fish and Wildlife Service will be working together to develop a restoration plan for the Pit River Hatchery site. The plan is expected to be completed by the spring of 1998.

Coordination with Landowners

Between 1990 and 1995, coordination between Maria Ellis and private landowners was initiated to develop partnerships for managing Shasta crayfish. These efforts included establishing communication, gaining permission to access properties for conducting surveys, and public education.

Research

Shasta Crayfish. Between 1990 and 1995, three projects were initiated to study and/or manage Shasta crayfish, supported by California Department of Fish and Game, in part, by Federal funds under provisions of section 6 of the Endangered Species Act. These projects included ecology and competition studies, competitor control and habitat improvement, and disease and fungus control studies.

A literature review of barriers and their effectiveness was conducted to determine what design would be appropriate to prevent nonnative crayfish from invading populations of Shasta crayfish (Ellis 1994b). An experimental design has been suggested that would prevent the upstream migration of crayfish, while allowing the passage of fish. It consists of an overhanging barrier constructed from bank to bank and extending between 0.31–0.46 meter (1.0–1.5 feet) above the substrate, acting as a physical and a velocity barrier (Figure 10). In low- or no-current areas, the height of the barrier would have to be increased since it would be functioning solely as a physical barrier. Field tests for crayfish barriers were included as part of the section 6 funded projects in 1994. These plans were changed, however, and restoration plans were developed in lieu of the field tests. No field testing of crayfish barriers has been conducted to date, but field testing is included as a task in this recovery plan.

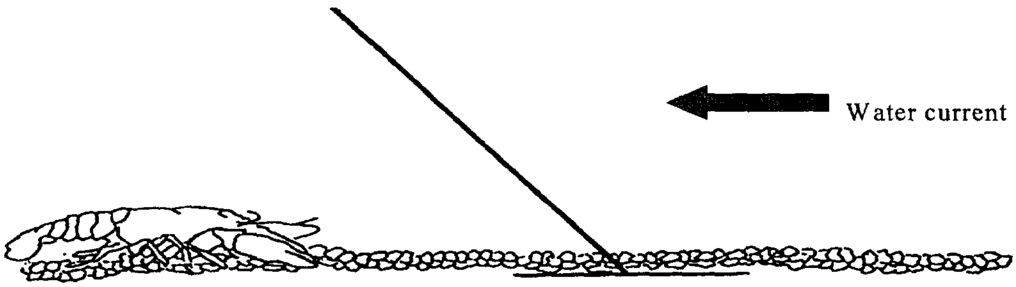

Figure 10. An example of a physical/velocity barrier to the upstream migration of crayfish.

Geothermal Development and Recharge Area Study. Concerns have been raised regarding the geothermal development of the Medicine Lake Highlands area before adequate research has been conducted (T. Grose *et al., in litt.* 1996 and 1997). A research proposal by the Lawrence Livermore National Laboratory and the Department of Geology, Colorado School of Mines (Davisson *et al.* 1997) would provide necessary information to determine whether geothermal development of the Medicine Lake Highlands would impact the springs of the Fall River and the Shasta crayfish that live there. This research should be conducted prior to any further exploration or development of the Medicine Lake Highlands.

Similar research conducted in the Hat Creek basin in 1993 ultimately showed that the proposed transfer of Lost Creek water to Hat Creek at Bidwell Ranch would have decreased the discharge of the springs in Rising River almost immediately (Rose 1994, Rose *et al.* 1996). If implemented, this transfer project would have resulted in a permanent decrease of greater than 20 percent in the discharge of the Rising River springs, which likely would have had a negative impact on the Rising River Shasta crayfish population.

Spring Creek Culvert Fortification and Monitoring

In November 1996, California Department of Fish and Game began working with Shasta County to excavate material from the downstream end of the culverts under Spring Creek (T. Healey, *in litt.* 1997). These culverts acted as velocity barriers to signal crayfish until the floods of January 1997, when the water backed up into Spring Creek from the Fall River. California Department of Fish and Game has also conducted two surveys since then to monitor the status and condition of the culverts and to eradicate signal crayfish upstream of the culverts. Eradication surveys should continue until no signal crayfish are found upstream of the culverts.

Upper Fall River

Habitat enhancement has been initiated in this area during the course of surveys for Shasta crayfish. Lava rocks covered by sediment were turned over and laid on top of the sediment to provide refugia for Shasta crayfish. This type of enhancement needs to continue on a regular basis as long as significant amounts of sediment are being transported.

The Fall River Resource Conservation District is currently directing the Fall River Sediment Study, which should be completed in May 1998. Maria Ellis has provided information at public meetings regarding potential impacts of projects on Shasta crayfish and has coordinated with and assisted the Fall River Resource Conservation District regarding such issues as muskrat control.

I. Consideration of Proposed and Candidate Species and Species of Concern

Special status species that occur within the range of Shasta crayfish and could potentially be impacted by recovery actions for the Shasta crayfish include the rough sculpin (State threatened and Federal species of concern), big-eyed marbled sculpin (State species of special concern), the California floater (a mussel) and Montane peaclam (Federal species of concern), the northwestern pond turtle (Federal species of concern), and the bald eagle (Federal threatened, State endangered). Actions recommended in this recovery plan that could benefit other rare endemics in the area include improving water quality in the Pit River drainage, reducing nonnative species, improving land management practices, and increasing public awareness regarding listed species. Some actions could possibly have negligible negative effects on special status species in the area.

Increasing the flow of water from the Fall River to the Pit River below the diversion dam would improve water quality for aquatic species in that section of the Fall River and the Pit River. A secondary benefit might be to improve prey populations for species feeding on aquatic life (e.g., bald eagle). The building of crayfish barriers could create temporary disturbance to species and habitats in the area of construction. Enhancing habitat by adding lava cobble and boulders along the levees could impact mussel habitat and cause disturbance or take of individuals. The impact is expected to be negligible because the habitat enhancement will be taking place along the levees where only a small percentage of mussels are found.

Recovery actions that protect riparian habitat and promote native plants on levees could enhance or protect habitat for terrestrial species in the area. Appendix B lists terrestrial vertebrate and plant species with special status that may occur in proximity to Shasta crayfish habitat but are highly unlikely to be impacted by recovery actions for the Shasta crayfish.

J. Recovery Strategy

The invasion of nonnative crayfish species, in particular signal crayfish, is the single largest threat to the continued existence of Shasta crayfish. The continued existence of Shasta crayfish would be ensured when the subpopulations of the seven remaining populations are protected from the invasion of nonnative species, particularly signal crayfish, and from other disturbances. Spring Creek and Rising River are the only two populations where **all** subpopulations are currently free of nonnative crayfish (Table 4). All of the Hat Creek and Pit River subpopulations have been invaded by nonnative crayfish. The remaining three populations (upper Fall River, Lava Creek and upper Tule River) have some invaded and some pure Shasta crayfish subpopulations (Table 4).

When all of the subpopulations that are currently free of signal crayfish are protected and considered stable (defined as self-sustaining populations comprising representatives of all age classes), Shasta crayfish could then be reclassified as

Table 4. Summary of the status of all known subpopulations within the eight geographically isolated populations of Shasta crayfish (see also Table 2).

Populations	Subpopulations[1]												
	Invaded by Nonnative Crayfish						Pure Shasta Crayfish					Total Existing	Total Extinct
	ID	S/D	S	D	NS	**Total**	S/D	S	D	NS	**Total**		
Upper Fall River		1	0	2	1	**4**		4			**4**	8	
Lava Creek				2		**2**	2	0			**2**	4	1
Upper Tule River		2		3		**5**	2	6			**8**	13	
Pit River	2	0		2		**4**					**0**	4	1?
Hat Creek				3	1	**4**					**0**	4	1
Spring Creek						**0**		2			**2**	2	
Rising River						**0**	3	1	0		**4**	4	
Fall River Mills (extinct)						**0**					**0**		1
TOTAL	**2**	**3**	**0**	**12**	**2**	**= 19**	**7**	**13**	**0**	**0**	**= 20**	**39**	**4**

[1] ID=insufficient data, S/D = stable or declining?, S = stable, D = declining, NS = not self-sustaining population (probably incidental sighting), ? = presumed

threatened. Recovery actions would then be focused on subpopulations that have been invaded by nonnative crayfish species. When signal crayfish are eradicated or controlled and these Shasta crayfish subpopulations are considered stable and protected from other disturbances, Shasta crayfish can be considered recovered and delisted.

The primary goal is to protect and stabilize the known Shasta crayfish subpopulations. This protection will maintain the genetic diversity of the species. Many tasks are primarily aimed at subpopulations that are currently free of nonnative crayfish, as well as a few select invaded subpopulations, and include designing, testing, and installing efficient crayfish barriers and maintaining some barriers (i.e., culverts and weirs) useful in preventing signal crayfish invasions. Other site-specific tasks include habitat restoration and enhancement, working with landowners, improving land use practices, eradicating signal crayfish, stabilizing river and stream banks with plantings, developing dredging alternatives, eliminating fish hatchery operations, and establishing fishing restrictions. Other tasks are directed at subpopulations of Shasta crayfish that already have signal crayfish. These tasks include stabilization of populations, eradication programs for signal crayfish, and habitat enhancement. Some of the suggested methods for achieving these goals are experimental, such as the design, construction, implementation, and maintenance of crayfish barriers.

Several tasks are required to develop an adequate barrier design. First, an extensive flume study (Appendix C.) should be conducted to determine the best barrier design. Second, a field test of the crayfish barrier design should be conducted along with a one-year monitoring/maintenance period during which different eradication methods can be employed upstream from the barrier to measure its effectiveness. The methods/techniques for the control and/or eradication of nonnative crayfish are also somewhat experimental and the likelihood of success is unknown. The probability of complete eradication of signal crayfish from large areas is low.

Another goal is to determine the distribution, status, and relative abundance of Shasta crayfish in the mainstem Pit River. Because the environment in the mainstem Pit River is much more variable than in other Shasta crayfish locations, this study should also examine the potential impacts of variations in discharge (e.g., habitat availability, flow velocity, and substrate stability), water quality, and temperature on the Pit River Shasta crayfish population.

Additional research is needed on the ecology and requirements of Shasta crayfish, the dynamics of Shasta crayfish behavior and interspecific interactions with invading species (signal crayfish and virile crayfish), and the importance and impact of signal crayfish and virile crayfish pathology on Shasta crayfish. This information is integral for the recovery and management of Shasta crayfish and for maintenance of self-sustaining populations that have representatives of all age classes. As new information becomes available, management strategies can be revised, and the information can be incorporated into any future revisions of this recovery plan.

II. RECOVERY

A. Objectives and Criteria

The primary objective of this plan is to stabilize and protect existing populations so that Shasta crayfish may be reclassified as a threatened species and ultimately delisted.

Criteria for Downlisting:

1. The 20 major subpopulations within 5 Shasta crayfish populations that are currently free of nonnative crayfish species (Table 2) are protected to ensure they remain isolated from nonnative crayfish species, and these subpopulations are stable (i.e., self-sustaining and comprising representatives of all age classes).

2. The Crystal Lake and Sucker Springs Creek subpopulations, which have been invaded by signal crayfish, are protected and stable due to elimination, reduction, or management of signal crayfish.

3. Over a 5-year period, population sizes remain constant at Upper Fall River, Spring Creek, and Rising River, and population sizes increase at Lava Creek, upper Tule River, Crystal Lake, and Sucker Springs.

4. Signal crayfish are eradicated in lower Lava Creek so that Shasta crayfish are free of signal crayfish throughout the entire Lava Creek subdrainage.

5. The major subpopulations in each of the seven Shasta crayfish populations are protected from disturbances related to land use practices.

Criteria for Recovery:

1. Nonnative crayfish species, in particular signal crayfish, have been eliminated, reduced, or are being managed in all Shasta crayfish subpopulations, so that they no longer threaten the continued existence of Shasta crayfish at these sites.

2. All Shasta crayfish subpopulations are stable, with population sizes that are increasing over a 5-year period.

B. Narrative Outline for Recovery Actions

1. <u>Protect the remaining populations of Shasta crayfish currently free of nonnative crayfish</u>.

Of the seven Shasta crayfish populations, five either have no nonnative crayfish species or have major subpopulations that have no nonnative crayfish (Table 4).

Protecting Shasta crayfish populations from signal crayfish invasions and other disturbances and ensuring their stability are the first priorities for recovery of Shasta crayfish. Two subpopulations, which have already been invaded by signal crayfish, are included in this section because the recovery tasks are the same as for populations that are currently free of signal crayfish.

1.1 Protect the upper Fall River population—currently free of signal crayfish.

The Thousand Springs fish trap cove and old property line, Fall River sand springs, and Rainbow Spring are still free of signal crayfish and represent the major subpopulations of the upper Fall River population and one of the larger populations of Shasta crayfish. Thousand Springs is considered the most pristine location where Shasta crayfish are found. Protection of this population is essential to the recovery effort.

1.1.1 Secure the cooperation of landowners to manage and protect Shasta crayfish.

The Thousand Springs and Rainbow Spring properties are privately owned and closed to the general public. The cooperation of both of these landowners is necessary to implement recovery actions relating to the management of Shasta crayfish and their habitat and the exclusion of nonnative crayfish. A cooperative agreement should be developed with the landowners to implement recovery actions related to the management of Shasta crayfish and their habitat and the exclusion of nonnative crayfish.

1.1.2 Install a crayfish barrier upstream of the Navigation Limit.

Construction of a physical/velocity barrier to stop the upstream advancement of signal crayfish is necessary to maintain and protect this major subpopulation of the upper Fall River population. A flume study (task 3.1) must be conducted prior to barrier installation.

1.1.3 Restore Bear Creek meadow.

Bear Creek meadow should be restored so that it ceases to be an active source of sediment into the Fall River (R. Poore, unpubl. data) and to restore its capability as a deposition area for sediment coming from the upper watershed. Restoration of Bear Creek meadow is an important step in reducing the sediment load that is currently threatening Shasta crayfish populations in the Fall River.

1.1.4 Enhance Shasta crayfish habitat upstream of the Navigation Limit.

All visible lava cobbles and boulders should be uncovered by turning the rocks over so that they are on top of the gravel, instead of covered by gravel. This can be accomplished by divers during monitoring surveys. If there is still a shortage after uncovering larger substrate, appropriate substrate can be imported by hand from the surrounding area. Appropriate substrate consists of large (at least 25.4 centimeters [10 inches] diameter) lava cobbles and boulders (approximately two to three large cobbles/small boulders per square meter [approximately one per every three feet]), generally on top of lava gravel. Emphasis should be placed on the area between Rainbow Spring outflow and the Navigation Limit.

1.2 Protect the Spring Creek population—free of signal crayfish.

Although both subpopulations in Spring Creek were formerly free of nonnative crayfish, signal crayfish were found upstream of the culverts on August 20, 1997, but had not invaded upstream into the Shasta crayfish populations. The breached area was surveyed and all signal crayfish were thought to have been removed. Eradicating all signal crayfish upstream of the culverts and protecting the Spring Creek subpopulations is essential to the recovery effort.

1.2.1 Secure the cooperation of landowners to manage and protect Shasta crayfish.

The Spring Creek property is privately owned and closed to the general public. The cooperation of this landowner is necessary to implement recovery actions related to the management of Shasta crayfish and their habitat. The cooperation of the downstream landowner is necessary to fortify the upstream migration barrier for the exclusion of nonnative crayfish. A cooperative agreement should be developed with the landowner to protect and manage Shasta crayfish in Spring Creek.

1.2.2 Eradicate all signal crayfish upstream of culverts.

Continue eradication surveys until no more signal crayfish are found upstream of the culverts for three to four consecutive years.

1.2.3 Monitor the barrier created by the four culverts at Spring Creek Road crossing and fortify if possible.

Examine and monitor the four culverts at Spring Creek Road crossing to determine and ensure that they are adequate physical/velocity barriers to the upstream migration of signal crayfish and fortify if possible. The possibility that signal crayfish could move overland across Spring Creek Road should also be considered and, if necessary, steps should be taken to prevent such movement.

1.2.4 Enhance Shasta crayfish habitat in lower fish trap cove.

Although there is ample, clean lava gravel in lower fish trap cove, there is a shortage of lava cobble and boulders. Appropriate substrate from the surrounding area should be placed in lower fish trap cove to enhance Shasta crayfish habitat. Because only a small amount of lava substrate would be necessary to enhance this relatively small area, lava substrate can be placed by hand so that the disturbance to Shasta crayfish is minimal.

1.3 Protect the Lava Creek population—some subpopulations have signal crayfish.

The Shasta crayfish subpopulations in the headwaters of the east and west arms of Lava Creek are still believed to be free of signal crayfish. Protection of these subpopulations from invading signal crayfish is essential to the recovery effort. Signal crayfish have invaded Lava Creek from Eastman Lake and continue to migrate upstream towards the headwaters of Lava Creek. Lava Creek has the largest nearly continuous expanse of Shasta crayfish habitat of any location. The return of this entire stream to a Shasta crayfish population free of signal crayfish would provide a valuable refuge for the species.

1.3.1 Secure the cooperation of landowners to manage and protect Shasta crayfish.

There are several private properties along Lava Creek. One of these properties is a fly-fishing club. Lava Creek is closed to the general public. The cooperation of these landowners is necessary to implement recovery actions related to the management of Shasta crayfish and their habitat and the exclusion of nonnative crayfish. A cooperative agreement should be developed with these landowners to protect and manage Shasta crayfish on their properties.

1.3.2 Survey Lava Creek for signal crayfish and install barriers and eradicate signal crayfish as appropriate.

If Lava Creek Shasta crayfish populations are still allopatric (free of signal crayfish) or the signal crayfish population there is small enough to successfully eradicate, install one barrier. If there are many signal crayfish, a series of smaller barriers in multiple locations to protect specific locations of Shasta crayfish may be appropriate.

1.3.2.1 Survey Lava Creek to determine the status of the crayfish invasion.

Document the abundance of signal crayfish to determine the appropriate management strategy.

1.3.2.2 Install crayfish barriers in both the east and west arms of Lava Creek.

As appropriate, a physical/velocity barrier should be constructed in both the east and west arms of Lava Creek upstream of the invasion front of signal crayfish. This barrier would stop the continued upstream advancement of signal crayfish into the headwaters. A flume study (task 3.1) must be conducted prior to barrier installation.

1.3.2.3 Install a crayfish barrier at the outflow of Lava Creek.

As appropriate, install a crayfish barrier at the outflow of Lava Creek into Eastman Lake (Tule River) and in the small drainage ditch on the west side to stop the invasion of signal crayfish from Eastman Lake. This barrier would minimize or reduce the source population of signal crayfish that could migrate into the headwaters of Lava Creek and be a first step towards securing Lava Creek as a population free of signal crayfish. A flume study (task 3.1) must be conducted prior to barrier installation.

1.3.2.4 Initiate a signal crayfish eradication program in Lava Creek.

Use baited traps and hand collecting to eradicate signal crayfish in Lava Creek. The control and/or eradication of signal crayfish will require repeated efforts, potentially over a period of years, to be successful. Trained people, preferably on-site land managers or owners of the property, should set multiple baited traps year round to trap as many signal crayfish as possible. Concurrent with the trapping effort, repeated surveys should be conducted by multiple divers to hand collect signal crayfish. The status of Shasta crayfish in the area can be monitored during these surveys, as well (task 4.2). The upstream barriers in the east and west arms can be removed ONLY AFTER it is determined that signal crayfish have been eradicated from Lava Creek (task 4.1), and that there are no potential pathogens, parasites, or commensals from signal crayfish being carried by Shasta crayfish (tasks 3.4.2.3 and 3.4.2.4).

1.4 Protect the upper Tule River population—free of signal crayfish.

Eight subpopulations of Shasta crayfish in the upper Tule River may still be free of signal crayfish: the six Big Lake subpopulations, the Ja-She Creek headwaters subpopulation, and the Crystal Springs, Cove and Inlet subpopulation. Protection of the Big Lake and Ja-She Creek headwater subpopulations is essential to the recovery effort. (Crystal Cove is so large that installing barriers is probably not realistic.)

1.4.1 Secure the cooperation of PG&E and the California Department of Parks and Recreation to manage and protect Shasta crayfish.

PG&E owns most of the land, river and lakebeds, and water rights in the upper Tule River subdrainage. PG&E also maintains the levee system where three Shasta crayfish subpopulations are found. The California Department of Parks and Recreation owns the property (i.e., Ahjumawi Lava Springs State Park) along the northern part of the subdrainage and the streambed of Ja-She Creek upstream of the state park road crossing (Ja-She Creek Bridge). The cooperation of PG&E and California Department of Parks and Recreation is necessary to implement recovery actions related to the management of Shasta crayfish and their habitat and the exclusion of nonnative crayfish. A cooperative agreement should be developed with PG&E and California Department of Parks and Recreation to protect and manage Shasta crayfish on their property. (This task also contributes to recovery goals for populations already invaded by signal crayfish in the upper Tule River population.)

1.4.2 Assess feasibility of installing a crayfish barrier at the outflow of Big Lake into the Tule River at Rat Farm and if appropriate, install barrier.

The constriction where Big Lake flows into the Tule River at Rat Farm is the only possible location where a physical upstream migration barrier could be built. Installation of a barrier at this location, which was upstream of the invasion front of signal crayfish at the time of the last survey, could prevent signal crayfish from invading Big Lake. A barrier would not, however, halt possible introduction of nonnative crayfish through the illegal use of crayfish as bait. A flume study (task 3.1) must be conducted prior to barrier installation. If feasible, install the barrier.

1.4.3 Install a crayfish barrier at Ja-She Creek Bridge on Ja-She Creek.

The construction of a physical/velocity barrier where Ja-She Creek flows under the Ahjumawi Lava Springs State Park road at Ja-She Creek Bridge would prevent signal crayfish from invading Ja-She Creek. A flume study (task 3.1) must be conducted prior to barrier installation.

1.4.4 Assess and develop a crayfish barrier for Crystal Cove and Crystal Inlet.

1.4.4.1 Assess feasibility of installing a crayfish barrier at Crystal Cove and Crystal Inlet.

Because the cove is fairly wide, it may not be feasible to build a barrier across it. The opening to Crystal Inlet is narrow enough, but the Crystal Inlet subpopulation of Shasta crayfish probably represents less than half of the total Crystal Cove population. The construction of a physical upstream migration barrier across Crystal Cove would prevent signal crayfish from invading both Crystal Cove and Crystal Inlet and protect the only subpopulation free of signal crayfish in lower Ja-She Creek. A flume study (task 3.1) must be conducted prior to barrier installation.

1.4.4.2 Install barrier at Crystal Cove.

If task 1.4.4.1 determines that it is feasible, install the barrier at Crystal Cove.

1.4.5 Initiate a signal crayfish eradication program upstream of all barriers.

Use baited traps and hand collecting to eradicate signal crayfish upstream of the barriers in the upper Tule River. The goal is to eliminate any nonnative crayfish in Big Lake, Ja-She Creek headwaters, and Crystal Cove.

1.4.6 Develop alternative levee maintenance practices.

Dredging should be replaced whenever possible by reconstruction of the levees using material trucked in from borrow pits. The material from borrow pits is more structurally sound than dredged material. Use of lava substrate would fortify the levees and create additional habitat for Shasta crayfish. An action plan must be developed prior to any lava placement to minimize the disturbance and impact on Shasta crayfish. To minimize disturbance, Shasta crayfish could be temporarily relocated to habitat nearby and replaced after levees are fortified. (If there is no adjacent habitat, substrate could be added to create a suitable relocation area.) Inaccessible stretches of levee, such as the state park levee, should be abandoned in place.

1.4.7 Enhance and create Shasta crayfish habitat.

Enhance Shasta crayfish habitat in all subpopulations in Big Lake and the Horr Pond levee except North Big Lake and Big Lake Spring subpopulations. Add appropriate substrate. An action plan must be developed prior to any lava placement to minimize the disturbance and impact on Shasta crayfish. Shasta crayfish could be temporarily relocated to habitat nearby and replaced after habitat enhancement. (If there is no adjacent habitat, substrate could be added to create a suitable relocation area.)

1.4.8 Plant levees and riparian areas with native plants.

Plant levees and riparian areas with perennial grasses and other native species to aid in bank stabilization. This would reduce the need for levee maintenance, increase bank stability, reduce sediment input, and result in less disturbance to Shasta crayfish populations in the vicinity of the levees and streambanks. Burn the existing vegetation on the levee before seeding. (This task also contributes to recovery goals for populations already invaded by signal crayfish in the area.)

1.5 Protect the Rising River population—free of signal crayfish.

The Rising River subdrainage, including Rising River, Rising River Lake, and the Rising River Lake outflow channel, contains the only Shasta crayfish population free of signal crayfish in the Hat Creek drainage. Protection of this population is essential to the recovery effort.

1.5.1 Secure the cooperation of landowners to manage and protect Shasta crayfish.

There are four private properties on the Rising River subdrainage. Rising River is closed to the general public. Shasta crayfish are located on the two upstream properties. The cooperation of both upstream landowners is necessary to implement recovery actions related to the management of Shasta crayfish and their habitat. The cooperation of the landowner upstream of the Cassel Bridge is necessary to implement recovery actions related to exclusion of nonnative crayfish. A cooperative agreement should be developed with these landowners to protect and manage Shasta crayfish on their properties.

1.5.2 Install a crayfish barrier on Rising River at the Cassel Road crossing.

The construction of a physical/velocity upstream migration barrier where Cassel Road crosses Rising River (3.1 kilometers [1.9 miles] upstream of the town of Cassel) would prevent signal crayfish from invading the majority of the Rising River subdrainage. This upstream migration barrier would protect all Rising River subpopulations of Shasta crayfish and a large expanse of suitable habitat that is not being used by Shasta crayfish, but probably would be suitable as refugia. A flume study (task 3.1) must be conducted prior to barrier installation.

1.6 Protect the Pit River subpopulations at Sucker Springs Creek—invaded by signal crayfish.

The largest concentration of Shasta crayfish in the midsections of the Pit River, one that was once free of signal crayfish, is located at Sucker Springs Creek in Pond 3 of the California Department of Fish and Game Pit River Hatchery. The hatchery was closed in 1997 and is in the process of being dismantled. As a result of the 1996 invasion of signal crayfish into Pond 3, this subpopulation is no longer free of signal crayfish, and its numbers have been dramatically reduced (Ellis 1997). Eradication of signal crayfish and restoration and protection of the Sucker Springs Creek subpopulation are essential to recovery of the Shasta crayfish.

1.6.1 Secure the cooperation of PG&E and California Department of Fish and Game to manage and protect Shasta crayfish.

The cooperation of PG&E, as the landowner, and California Department of Fish and Game, as the previous lessee, is necessary to implement recovery actions related to management of Shasta crayfish and their habitat and the exclusion of nonnative crayfish.

1.6.2 Ensure that the weirs between all Ponds (Ponds 1,2,3,4, and 5) and downstream of Pond 5 are kept in place.

These weirs act as barriers to the upstream migration of signal crayfish. Ensuring that all of these weirs (including the flashboards) are kept in place will prevent further upstream migration of signal crayfish into the Shasta crayfish population in Sucker Springs Creek. Replace flashboards if necessary to ensure the integrity of the barrier.

1.6.3 Restore habitat in Ponds 1 and 2 and relocate Shasta crayfish from Ponds 2 and 3.

Eradication of signal crayfish in Pond 3 will result in substantial habitat disturbance and potential impacts to individual Shasta crayfish. Restoring habitat in Ponds 1 and 2 will create refugia to relocate Shasta crayfish to during eradication and restoration procedures in Pond 3. Restoration in Ponds 1 and 2 will also create additional habitat in Sucker Springs Creek.

1.6.3.1 Restore Shasta crayfish habitat in Ponds 1 and 2.

Remove the fencing/revetment along the north banks of Ponds 1 and 2. Remove cement walls, walkways and revetments on the south side of the ponds and return the bank and channel to natural conditions by rearranging lava boulder and cobbles and importing more lava substrate if necessary.

1.6.3.2 If Shasta crayfish are found in Pond 2, without signal crayfish present, relocate Shasta crayfish to Pond 1.

During task 1.6.3.1, there is the remote possibility of finding some Shasta crayfish behind the fencing/revetment in Pond 2 that were not detected previously. If any Shasta crayfish are found in Pond 2 and NO SIGNAL CRAYFISH are found, move these Shasta crayfish to Pond 1. (This step is necessary to avoid contaminating any Shasta crayfish in Pond 2 that have never been exposed to signal crayfish disease and/or commensals). The weir between Ponds 1 and 2 should be maintained.

1.6.3.3 Relocate Shasta crayfish from Pond 3 to Pond 2.

Once Pond 2 is restored and Shasta crayfish are relocated to Pond 1 (if they have had no exposure to signal crayfish), relocate all Shasta crayfish from Pond 3 to Pond 2. Boulders and cobbles should be removed carefully along the north and south banks of Pond 3 so that all Shasta crayfish can be recovered and moved to Pond 2.

1.6.4 Initiate a signal crayfish eradication program in Ponds 3 and 4.

Once task 1.6.3.3 is completed, initiate an eradication program in Ponds 3 and 4 using baited traps and hand removal. Eradication will be considered complete if signal crayfish are not found during complete surveys for 3–4 consecutive years.

1.6.5 Restore habitat in Pond 3.

Enhance crayfish habitat in Pond 3 by relocating appropriate substrate by hand from the banks and hillside into the channel. Import additional lava rock if necessary. Remove cement walls, walkways and revetments on the south side of the pond and return the bank and channel to natural conditions by rearranging lava boulder and cobbles and importing more lava substrate if necessary.

1.6.6 Install a crayfish barrier at the mouth of Sucker Springs Creek.

Install a crayfish barrier at the mouth of Sucker Springs Creek to prevent further invasion of signal crayfish from the Pit River. A flume study (task 3.1) must be conducted prior to barrier installation.

1.6.7 Initiate a signal crayfish eradication program in Sucker Springs Creek downstream of Pond 3.

Implement a program to eradicate signal crayfish in Sucker Springs Creek, downstream of Pond 3, using baited traps and hand collection.

1.6.8 Evaluate status of Shasta crayfish subpopulation in Sucker Springs and, if appropriate, remove all barriers between Ponds 3, 2, and 1.

After tasks 1.6.3, 1.6.5, and 1.6.6 are completed and the criteria are met for determining that signal crayfish have been eradicated (see task 1.6.4), if appropriate, remove barriers between Ponds 3, 2, and 1 and allow crayfish to colonize all available habitat.

1.7 Restore Sucker Springs Creek upstream of hatchery.

Restoration of Sucker Springs Creek upstream of the hatchery could potentially provide habitat for Shasta crayfish.

1.7.1 Remove the dam and culvert upstream of the hatchery.

Removal of the dam and culvert would restore normal flow in the channel upstream of the hatchery, which would flush out some of the sediment that has accumulated over the last 10 years.

1.7.2 Remove sediment upstream of the hatchery, if necessary.

If removing the dam is not sufficient to wash away sediment that has accumulated upstream of the dam, sediment should be removed mechanically.

1.7.3 Add substrate upstream of the hatchery, if necessary.

If there is not enough gravel in the stream channel once sediment is removed, appropriate substrate should be imported. Lava cobbles and boulders should be placed in the stream channel upstream of the hatchery.

2. Protect and enhance populations of Shasta crayfish invaded by signal crayfish.

Signal crayfish have invaded parts of five of the seven Shasta crayfish populations. Although the complete eradication of signal crayfish from all of these populations may not be feasible, the protection and enhancement of these populations is important for the recovery and management of Shasta crayfish.

2.1 Protect and enhance the Hat Creek, Cassel population—invaded by signal crayfish.

Crystal Lake has the only self-sustaining population of Shasta crayfish in the Hat Creek, Cassel population area. Signal crayfish have been in Crystal Lake with Shasta crayfish since 1978. This population may hold the answer to two major questions that are vital to the recovery effort: (1) What caused the decrease (i.e., predation, competition, disease) in Shasta crayfish abundance after invasion by signal crayfish, and (2) how/why has approximately 10 percent of the estimated population survived?

2.1.1 Secure the cooperation of PG&E and California Department of Fish and Game to manage and protect Shasta crayfish.

The cooperation of PG&E and California Department of Fish and Game is necessary to implement recovery actions related to the management of Shasta crayfish and their habitat and to eradicate or control nonnative crayfish. A cooperative agreement should be developed with PG&E and California Department of Fish and Game to protect and manage Shasta crayfish on this property.

2.1.2 Install a crayfish barrier at the outflow of Crystal Lake into Baum Lake.

Install an upstream migration barrier at the outflow of Crystal Lake to prevent the further invasion of signal crayfish from Baum Lake. A flume study (task 3.1) must be conducted prior to barrier installation.

2.1.3 Initiate a signal crayfish eradication program in Crystal Lake.

Baited traps and hand collections should be used in a signal crayfish eradication program in Crystal Lake. Installing temporary barriers would allow eradication within smaller areas.

2.1.4 Improve land use practices at Crystal and Baum Lakes.

PG&E leases grazing privileges at Crystal and Baum Lakes, and has contracted for salvage logging of diseased trees in the Hat Creek drainage, including Crystal Lake. These activities have contributed to surface runoff, sedimentation, and eutrophication of these lakes.

2.1.4.1 Exclude or remove cattle from the riparian zone of Crystal and Baum Lakes.

Work with PG&E to exclude or remove cattle from Crystal and Baum Lakes, to prevent cattle from grazing the riparian area and wading into the lakes.

2.1.4.2 Develop waterway protection zones around the lakes.

Work with PG&E to develop waterway protection zones around the lakes to prevent grazing, logging, or other potentially harmful practices from occurring close to the lakes.

2.1.5 Institute fishing restrictions at the outflow of Crystal Lake.

All fishing in the outflow area of Crystal Lake downstream from the hatchery intake (i.e., the area approximately 100 meters [325 feet] upstream of the outflow) should be closed to minimize disturbance to Shasta crayfish from wading.

2.2 Protect and enhance the upper Tule River subpopulation if feasible—invaded by signal crayfish.

Shasta crayfish in the Tule Coves should be protected and signal crayfish should be eradicated from these areas. In addition, signal crayfish have also invaded the upper Tule River into the east- and south-shore subpopulations of Shasta crayfish. The south- and east-shore upper Tule River subpopulations would be greatly enhanced by the addition of lava substrate to create Shasta crayfish habitat. The size of the watercourse and the location of the east- and south-shore subpopulations do not lend themselves to the construction of barriers.

2.2.1 Install crayfish barriers at the entrances of east and west Tule Coves.

The construction of a physical upstream migration barrier at the entrance of east and west Tule Coves would stop the invasion of signal crayfish. A flume study (task 3.1) must be conducted prior to barrier installation.

2.2.2 Initiate a signal crayfish eradication program in Tule Coves.

Once the barriers are in place, use baited traps and hand collections to remove signal crayfish in east and west Tule Coves.

2.2.3 Enhance habitat for Shasta crayfish habitat along the upper Tule River.

Enhance Shasta crayfish habitat along the east and south shores of upper Tule River by adding appropriate lava substrate. Prior to any lava placement, a plan must be developed to minimize disturbance and impacts to Shasta crayfish. Shasta crayfish could be temporarily relocated to habitat nearby and replaced after the levees are fortified. (If there is no adjacent habitat, substrate could be added to create a suitable relocation area).

2.2.4 Remove or control muskrat populations in the watershed.

The control and/or eradication of muskrat populations in the watershed would be beneficial to Shasta crayfish by reducing sedimentation and loss of habitat and by reducing predation. Potential control/removal programs should be explored and tested in the field.

2.3 Protect and enhance the Pit River Population in the mainstem Pit River—invaded by signal crayfish.

Recent findings of Shasta crayfish in two locations in the mainstem Pit River (Pit River Falls, Pit River Canyon Springs) renew hope that Shasta crayfish are found throughout the section of the Pit River between the historic mouth of the Fall River and the confluence with Hat Creek.

2.3.1 Secure the cooperation of PG&E to manage and protect Shasta crayfish.

PG&E owns most of the land, including the riverbed, along the midsections of the Pit River. A cooperative agreement should be developed with PG&E to protect and manage Shasta crayfish on this property.

2.3.2 Determine the status, distribution, and relative abundance of Shasta crayfish in the mainstem Pit River.

Conduct a thorough scuba/snorkel survey of at least the margins of the entire Pit River between the historic confluence of Fall River and the confluence of Hat Creek to determine the status, distribution, and relative abundance of Shasta crayfish in the mainstem Pit River. Scuba gear is necessary to conduct thorough Shasta crayfish surveys, unless water depth is less than 60 centimeters (2 feet). Because it is difficult to access the Pit River Canyon upstream of the Pit 1 Powerhouse, this section should be surveyed over an approximately 1- to 2-week period using an inflatable raft for support so that surveyors could camp overnight. The Pit River Canyon section should be surveyed when the flow in the river is low, but before the river is eutrophic; depending on the season, eutrophication would probably occur in late June to July. The Pit River downstream from the Pit 1 Powerhouse can be accessed at a number of locations by dirt roads. This section should be surveyed in the mornings before Pit 1 Powerhouse increases the flow.

2.3.3 Restore a continuous release of water through the Fall River into the Pit River.

Improving water quality by releasing water continuously through the Fall River would benefit Shasta crayfish in the mainstem of the Pit River. The ideal amount of water flow needed for Shasta crayfish is unknown at this time; however, any increase of water flow in the Pit River above Pit 1 powerhouse would improve water quality, which should improve conditions for Shasta crayfish.

2.4 Protect and enhance the upper Fall River population—invaded by signal crayfish.

2.4.1 Work with agencies to include Shasta crayfish in management/restoration plans for the Fall River.

The Fall River Resource Conservation District, in conjunction with California Department of Fish and Game, the Central Valley Region of the State Water Quality Control Board, and other agencies and researchers, are currently working on a study and restoration plan for the Fall River (see "Fall River Sediment Study"). The protection and enhancement of Shasta crayfish should be included in this plan.

2.4.2 Enhance Shasta crayfish habitat.

Uncover all visible lava cobbles and boulders at Fletcher's Bend and Lennihan's Footbridge by turning rocks over so that they are on top of, instead of covered by, the gravel and sediment. This enhancement can be accomplished by divers during monitoring surveys. If there is still a shortage after uncovering larger cobbles and boulders, appropriate substrate can be imported from the surrounding area.

2.4.3 Assess feasibility of installing site-exclusion barriers around Shasta crayfish habitat and install barriers if feasible.

Installation of site-exclusion barriers would protect small Shasta crayfish subpopulations and "islands" of Shasta crayfish habitat from the invasion of signal crayfish. Because Shasta crayfish do not appear to migrate far, site-exclusion barriers would have minimal impact on them. If site-exclusion barriers are mechanically feasible, install barriers around the subpopulations at Fletcher's Bend and Lennihan's Footbridge. A flume study (task 3.1) must be conducted prior to barrier installation.

2.4.4 Implement signal crayfish eradication program.

If site-exclusion crayfish barriers are installed (task 2.4.3), implement an eradication program for signal crayfish within the barriers.

2.4.5 Collaborate with private organizations to include the Shasta crayfish in restoration plans for the Fall River.

The protection and enhancement of Shasta crayfish in the Fall River should be included in any plan to restore the Fall River.

3. Conduct necessary research to develop effective management plans for the Shasta crayfish.

3.1 Design and conduct flume studies to develop and test crayfish barrier designs.

Large-scale flume studies should be designed and conducted to test the effectiveness of barrier designs using signal and virile crayfish under different velocity regimes, including no flow (i.e., complete physical barrier), and to determine the impacts of sediment transport and vegetation on barrier effectiveness. Studies should be completed for all site conditions before any barriers are installed within the range of the Shasta crayfish (see Appendix C). There are a number of flumes already established by researchers studying flow velocities that could be potential sites for Shasta crayfish studies.

3.2 Determine the recharge area (source of water) for the Fall River and protect it from potential disturbances.

The Medicine Lake Highlands are thought to be the recharge area for the Fall River. Proposed geothermal development has the potential to negatively impact Shasta crayfish in the Fall River. Research should be conducted to determine where the recharge areas are for the Fall River and their degree of interconnectivity with the springs in the midsections of the Pit River drainage. These recharge areas should be protected from all potential disturbances, such as geothermal development and water diversions.

3.3 Estimate Shasta crayfish abundance and develop targets for a sustainable and well-distributed population.

Analyze available survey data to estimate population and subpopulation densities, if feasible. If more survey data are needed to establish appropriate population parameters, develop and implement surveys to collect data to complete the analysis. Determine population targets for recovery.

3.4 Continue research on the ecology, behavior, and pathology of Shasta crayfish.

Management of Shasta crayfish populations requires a working knowledge of Shasta crayfish ecology, including food requirements and nutrition. Management of Shasta crayfish populations invaded by nonnative crayfish requires control of nonnative crayfish populations and determination of the major mechanisms regulating species replacement (i.e., the replacement of Shasta crayfish by signal crayfish). Determining the effects of interspecific interactions, including competition, predation, commensals, and pathology, will facilitate the development and implementation of management plans for Shasta crayfish. All studies should be designed to maximize the potential benefits to the species (i.e., information that can be used to help manage and protect the species), while minimizing the impacts, disturbance, and potential mortality to Shasta crayfish.

3.4.1 Determine food preferences and nutritional requirements of Shasta crayfish.

Determine the food preferences, nutritional needs, and foraging area requirements for self-sustaining populations of Shasta crayfish. Determine the age-specific food habits throughout the range. Determine the importance of seasonally abundant potential food resources such as sucker, trout, and sculpin eggs. If seasonal food resources are important to Shasta crayfish, then Shasta crayfish habitat should be redefined to include the presence of these seasonal food sources.

3.4.2 Determine the effects of signal crayfish on Shasta crayfish.

3.4.2.1 Determine the effects of signal crayfish competition and predation on Shasta crayfish.

Determine the importance and role of exploitative competition, interference competition, and predation by signal crayfish on Shasta crayfish. Determine the impacts of age, size, and aggressive dominance and other behaviors in these interactions. Current research (Ellis submitted) will clarify the competitive effects of signal crayfish on the behavior, use of refugia, and activity level of Shasta crayfish and the impact of a two-fold size advantage of signal crayfish in these interactions. Further research is necessary to determine the effects of competitive interactions on Shasta crayfish growth and to determine if competition and predation are major mechanisms regulating species replacement.

3.4.2.2 Determine the effects of matings between Shasta crayfish and signal crayfish.

Determine the importance and role of interspecific matings between signal crayfish and Shasta crayfish and the resulting negative effects on production of offspring (reproductive interference) by Shasta crayfish. Determine the impacts of size, gender, and behavior in these interactions. Determine if interspecific matings and reproductive interference are a major mechanism regulating species replacement.

3.4.2.3 Determine the impact of pathogens introduced to Shasta crayfish by signal crayfish.

Determine the impact of diseases, such as the crayfish plague, that may be carried by invading signal crayfish. Determine the importance and effect of fungal, protozoan, bacterial, and viral pathogens on Shasta crayfish. Determine the role that pathogens have played in the decline of Shasta crayfish populations, such as Crystal Lake.

3.4.2.4 Determine the effects of incidental secondary invaders from signal crayfish, such as commensal branchiobdellidan worms and ostracods, on Shasta crayfish.

Determine if the commensal organisms typical of signal crayfish are hosts or carriers of diseases or parasites to which Shasta crayfish are not resistant. Determine if commensal branchiobdellidan worms and ostracods have had a negative effect on Shasta crayfish and contributed to the decline of Shasta crayfish abundance in populations invaded by nonnative crayfish.

3.4.3 Determine the effects of virile crayfish on Shasta crayfish.

Determine the importance and role of competition, predation, interspecific matings and reproductive interference by virile crayfish on Shasta crayfish. Determine the importance and role of pathogens and commensals imported into Shasta crayfish populations by virile crayfish. Determine the major mechanisms regulating species replacement.

3.4.3.1 Determine the effects of virile crayfish competition and predation on Shasta crayfish.

Determine the importance and role of exploitative competition, interference competition, and predation by virile crayfish on Shasta crayfish. Determine the impacts of age, size, and aggressive dominance and other behaviors in these interactions.

3.4.3.2 Determine the effects of interspecific matings and reproductive interference of virile crayfish on Shasta crayfish.

Determine the importance and role of interspecific matings and reproductive interference by virile crayfish on Shasta crayfish. Determine the impacts of size, gender, and behavior in these interactions. Determine if interspecific matings and reproductive interference are a major mechanism regulating species replacement.

3.4.3.3 Determine the impact of pathogens introduced to Shasta crayfish by virile crayfish.

Fungal, protozoan, bacterial, and viral pathogens may be carried into Shasta crayfish populations by invading virile crayfish. Determine the importance and effect of these pathogens on Shasta crayfish.

3.4.3.4 Determine the effects of incidental secondary invaders from virile crayfish, such as commensal branchiobdellidan worms and ostracods, on Shasta crayfish.

Determine if the commensal organisms typical of virile crayfish are hosts or carriers of diseases or parasites to which Shasta crayfish are not resistant. Determine if commensal branchiobdellidan worms and ostracods have had a negative effect on Shasta crayfish and contributed to the decline of Shasta crayfish abundance in populations invaded by virile crayfish.

3.5 Conduct genetic studies on Shasta crayfish subpopulations, if feasible.

If genetic studies can be conducted using claws, walking legs, or other parts of Shasta crayfish that can be regenerated, then studies could determine whether subpopulations and populations are genetically distinct from each other. Determining the amount of genetic diversity both within and between subpopulations would clarify the amount of movement and exchange that occurs between subpopulations.

This information would have to be obtained before any Shasta crayfish are moved, reintroduced, or added to supplement existing populations, because these activities would contaminate potentially distinct gene combinations. This genetic information will be forever obscured if Shasta crayfish from different subpopulations are combined and they interbreed. In addition, if some of the small Shasta crayfish populations have already gone through severe inbreeding so that deleterious genes have been deleted, the introduction of Shasta crayfish with different genomes (sets of chromosomes) could have a negative impact on the population. Because the sacrifice of any individuals is considered to be extremely costly given the estimated size of subpopulations and the total Shasta crayfish population, the relative benefits of this information would have to be considered against the costs if individuals need to be sacrificed to conduct these studies.

4. Monitor and assess Shasta crayfish populations and modify management plans as necessary.

Continued monitoring of Shasta crayfish populations is necessary to determine the success of management and when recovery is achieved. Monitoring of populations upstream of barriers is necessary to ensure that these barriers are completely effective. Surveys should be ongoing to assess long-term population trends and to help identify management needs. Management plans will be revised to incorporate new information as necessary.

4.1 Periodically monitor the status of signal crayfish eradication in invaded populations.

Once eradication of signal crayfish appears to be complete, follow-up surveys of the area should be conducted to determine whether signal crayfish have been 100 percent eradicated and to determine whether crayfish barriers are successfully keeping signal crayfish from invading. The frequency of follow-up checks would be determined on a case-by-case basis based on the effectiveness of the barrier.

4.2 Monitor status of Shasta crayfish populations annually.

Monitor Shasta crayfish populations yearly to determine their status and relative abundance and to determine the presence/absence of nonnative crayfish species. See Appendix D for monitoring methods. Monitoring would also determine whether crayfish barriers are effectively keeping out nonnative crayfish.

4.3 Monitor crayfish barriers.

The integrity of crayfish barriers should be monitored several times a year. Visual inspection of barriers would be necessary immediately after major storms and runoff. Any sediment, vegetation, or debris built up on the barrier would need to be cleaned off as soon as possible.

5. Develop effective watershed and ecosystem management plans for all drainages supporting Shasta crayfish populations.

The watershed for the Shasta crayfish is defined as the midsection of the Pit River drainage, which includes the Fall River and Hat Creek subdrainages. The Bear Creek drainage should be included in the management plan because sediment transport from the Bear Creek drainage impacts Fall River. Proper watershed management is necessary to minimize impacts on Shasta crayfish. Watershed and ecosystem management will benefit other rare endemics, in addition to Shasta crayfish.

5.1 Work with landowners and managers to improve management practices.

A cooperative effort with landowners and managers would help protect the watershed where Shasta crayfish occur or are impacted downstream. Many landowners are already very good stewards and are practicing measures to safeguard the quality of habitat on their land. It is useful to periodically review management practices and improve them to minimize impacts on the species. Examples still exist of cattle grazing in riparian areas and along levees, which results in increased erosion and elevated sediment and nutrient loading. Other land management practices that may impact Shasta crayfish include timber harvest, bridge construction, and agriculture.

5.2 Modify and enforce regulations to aid in control of nonnative species.

The control of nonnative species populations through modification and enforcement of regulations and the prevention of any introductions of new exotic species in the watershed is essential to the recovery and management of Shasta crayfish and the ecosystem.

5.2.1 Change the fishing regulations for crayfishing.

To aid in removing signal crayfish from the watershed, areas where crayfishing is allowed should be expanded to include the Fall River from Spring Creek Bridge to the confluence with the Pit River; in Eastman Lake and Little Tule River, exclusive of tributaries; Hat Creek from Cassel Pond to the confluence with the Pit River, exclusive of tributaries; and Lake Britton.

5.2.2 Enforce the restriction on the use of crayfish as bait.

The restriction on the use of crayfish as bait should be strongly enforced. Enforcement could be facilitated through public awareness (see task 6). In addition, potential rewards for tips or reports of violators might aid enforcement. The effectiveness of increased enforcement efforts should be evaluated and the potential for additional funding explored.

5.2.3 Increase enforcement of regulations to prohibit the introduction of any new exotic species.

Increased enforcement of Section 671, Title 14, California Code of Regulations would more effectively reduce the introduction of any new exotic species, plant or animal. It is very difficult either to predict the range of impacts from introductions or to eradicate introduced species once they are established.

5.3 Establish/regulate water quality standards in the watershed in cooperation with the Central Valley Region of the State Regional Water Quality Control Board.

Good water quality is necessary for the health of the watershed and the ecosystem it supports, including Shasta crayfish.

5.3.1 Work with landowners and managers to update irrigation systems to benefit water quality.

Update irrigation systems, particularly in the headwaters areas, to ensure that irrigation return flows can settle before they re-enter the rivers. Improved irrigation systems should limit nutrient and fine organic sediment loading.

5.3.2 Explore potential effects of agricultural chemicals, including insecticides, herbicides, and fertilizers, in runoff and return flow within the drainage.

In cooperation with the Central Valley Region of the Regional Water Quality Control Board, determine the impact of agricultural chemicals, including insecticides, herbicides, and fertilizers, in runoff and return flow within the drainage. Special emphasis should be placed on conducting an updated investigation of the effects of wild rice farming on water quality. Explore ways to minimize identified impacts.

6. Provide public information and education.

Inform the general public about the threats to and the status of Shasta crayfish. Such a program will benefit the recovery effort and will serve to increase awareness of the causes of the species' endangerment. To counteract the perception that "endangered crayfish are found everywhere," inform the public that there are also two introduced, nonnative species of crayfish, which are not federally listed, living in the area . Increasing public awareness of the dangers of introduction might reduce the possibilities of introductions of other nonnatives. Increasing public awareness of the fishing regulation restricting the use of crayfish as bait in the midsections of the Pit River may help curtail bait-fishing with crayfish.

6.1 <u>Post signs at the Rat Farm and Tule River boat accesses and other public use areas</u>.

Signs could be posted at the Rat Farm and Tule River boat accesses, campgrounds, and other public use areas within the range of the Shasta crayfish to inform the public about the Shasta crayfish and state the fishing regulation prohibiting the use of crayfish as bait.

6.2 <u>Submit articles periodically in the two local papers to increase public education and awareness.</u>

Articles about Shasta crayfish in the local and Redding newspapers would increase public awareness. The recreation supplements from local and Redding papers are often made available to motel patrons as well.

6.3 <u>Make presentations at local primary and secondary schools</u>.

Increase the awareness of the local youth about the ecology and plight of the Shasta crayfish by giving yearly presentations. Involve school children with recovery and management of the species.

6.4 <u>Provide interpretive information to visitors at the Ahjumawi Lava Springs State Park</u>.

Supply brochures and/or interpretive signs to increase public awareness about Shasta crayfish.

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Personal Communications

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Don Weidlein, Senior Biologist (Marine/Fishery), Region I, California Department of Fish and Game, Redding, California; June 19, 1996.

In Litt. References

Elliot, Richard L., Regional Manager, Region 1, California Department of Fish and Game, Redding, California, in memorandum dated May 8, 1995 to Tim Farley, Chief, Inland Fisheries Division, California Department of Fish and Game, Sacramento, California.

Grose, T., Fall River Resource Conservation District (letters dated December 4, 1996 and May 20, 1997).

Healey, Terry, Associate Fisheries Biologist, Region 1, California Department of Fish and Game, Redding, California, in memorandum dated July 7, 1997 to Chuck Knutson, Inland Fisheries Division, California Department of Fish and Game, Sacrlamento, California.

Poore, R., T. Grose, and M. Ellis in letter dated June 4, 1997, from Fall River Resource Conservation District, McArthur, California, to R. Sharp, U.S. Forest Service, Alturas, California, commenting on the Telephone Flat Project in the Medicine Lake Highlands Area.

IV. IMPLEMENTATION SCHEDULE

The Implementation Schedule that follows is a summary of actions and estimated costs for this recovery plan. It is a guide to meet the objectives, identifies agencies responsible for performing each task, and estimates total costs for each task. These actions, when accomplished, will satisfy the recovery objectives. Initiation of these actions is subject to the availability of funds.

Priorities in Column 1 of the following implementation schedule are assigned as follows:

Priority 1 - An action that must be taken to prevent extinction or to prevent the species from declining irreversibly.

Priority 2 - An action that must be taken to prevent a significant decline in species population/habitat quality, or other significant adverse impact short of extinction.

Priority 3 - All other actions necessary to provide for full recovery of Shasta crayfish.

Key to Acronyms Used in the Implementation Schedule

FWS	= U.S. Fish and Wildlife Service
CDFG	= California Department of Fish and Game
NRCS	= Natural Resources Conservation Service
RWQCB	= California Regional Water Quality Control Board, Central Valley Region
COE	= Army Corps of Engineers
SCG	= Shasta County Government
PG&E	= Pacific Gas and Electric Company
CDPR	= California Department of Parks and Recreation

Key to Other Codes Used in the Implementation Schedule

*	= Lead agency
Ongoing	= Task is currently being implemented and will continue until action is no longer necessary for recovery.
Continuous	= Task will be implemented on an annual basis once it is begun.
TBD	= To be determined after plans or studies are done or decisions made
Total Costs	= Projected cost of task from start to completion.

Recovery Plan Implementation Schedule for the Shasta Crayfish

Priority #	Task #	Task Description	Task Duration (Years/Months)	Responsible Party	Total Cost	Cost Estimates ($1000) FY98	FY99	FY00	FY01	FY02
1	3.1	Design and conduct flume studies	1 yr	FWS* CDFG	20	20				
Upper Fall River (population free of signal crayfish)										
1	1.1.1	Work with landowners	Ongoing	FWS* CDFG	1	0.25	0.25	0.25	0.25	
1	1.1.2	Install barrier above Navigation Limit	3 mo	FWS* CDFG, NRCS	500		500			
1	1.1.3	Restore Bear Creek meadow	3 yr	RWQCB* NRCS, COE, CDFG, SCG	TBD	TBD	TBD	TBD		
1	1.1.4	Enhance habitat	2 yr	FWS* CDFG	1		0.5	0.5		
Upper Fall River (population invaded by signal crayfish)										
2	2.4.1	Develop management/ restoration plans	Ongoing	CDFG* RWQCB, COE NRSC, FWS	TBD					
2	2.4.2	Enhance habitat	Ongoing	FWS* CDFG	5-10	2-4	3-6			
2	2.4.3	Develop plan for site-exclusion barriers	2 mo	FWS* CDFG	52			52		

Recovery Plan Implementation Schedule for the Shasta Crayfish

Priority #	Task #	Task Description	Task Duration (Years/Months)	Responsible Party	Total Cost	Cost Estimates ($1000) FY98	FY99	FY00	FY01	FY02
2	2.4.4	Eradicate signal crayfish upstream of barriers	5 yr	FWS* CDFG	15	2	2	2	2	2
2	2.4.5	Collaborate on restoration with private organizations	Ongoing	CDFG* RWQCB, NRCS	TBD					
Spring Creek										
1	1.2.1	Work with landowners	Ongoing	FWS* CDFG, NRCS	1	0.25	0.25	0.25	0.25	
1	1.2.2	Eradicate signal crayfish upstream of culverts	Ongoing	CDFG	7	1	3	1	1	1
1	1.2.3	Monitor and maintain culverts at Spring Creek Road crossing as barriers	Ongoing	FWS* CDFG, SCG	16	5	10	0.5	0.5	
2	1.2.4	Enhance habitat in lower fish trap cove	1 yr	FWS* CDFG	1	1				

Recovery Plan Implementation Schedule for the Shasta Crayfish

Priority #	Task #	Task Description	Task Duration (Years/Months)	Responsible Party	Total Cost	Cost Estimates ($1000) FY98	FY99	FY00	FY01	FY02
Lava Creek										
1	1.3.1	Work with landowners	Ongoing	FWS* CDFG, NRCS	1	0.25	0.25	0.25	0.25	
1	1.3.2.1	Survey Lava Creek for signal crayfish	<1 mo	CDFG* FWS	1	1				
1	1.3.2.2	Install barrier in east and west arms	6 mo	FWS* CDFG	TBD		TBD			
1	1.3.2.4	Eradicate signal crayfish upstream of barriers	Continuous	FWS* CDFG	105	25	25	10	10	10
2	1.3.2.3	Install barrier at outflow of Lava Creek	3 mo	FWS* CDFG	150		150			
Upper Tule River										
1	1.4.1	Work with landowners	Ongoing	FWS*, CDFG, PG&E, CDPR, NRCS	1	0.25	0.25	0.25	0.25	
1	1.4.3	Install barrier at Ja-She Creek Bridge	3 mo	FWS* CDFG, CDPR	100		100			
1	1.4.5	Eradicate signal crayfish	Continuous	FWS* CDFG	190	50	50	25	10	

Recovery Plan Implementation Schedule for the Shasta Crayfish

Priority #	Task #	Task Description	Task Duration (Years/Months)	Responsible Party	Total Cost	Cost Estimates ($1000) FY98	FY99	FY00	FY01	FY02
2	1.4.6	Develop alternatives to dredging to maintain levees	Ongoing	PG&E* COE, FWS CDFG	TBD					
2	2.2.1	Install barriers at east and west Tule Cove entrances	6 mo	FWS* CDFG	TBD	TBD				
2	2.2.2	Eradicate signal crayfish at coves	Continuous	FWS* CDFG	100	15	15	15	15	15
2	2.2.3	Enhance habitat along upper Tule River	Ongoing	FWS* PG&E, COE	200		100	50	50	
2	1.4.7	Enhance and create habitat in Big Lake and Horr Pond	Continuous	FWS* PG&E, COE	200		100	50	50	
3	1.4.8	Use native plants to stabilize banks and levees	3 yr	PG&E* COE, CDFG	50		20	20	10	
3	1.4.2	Assess/install crayfish barrier at Big Lake outflow near Rat Farm	3 mo	FWS* CDFG, COE	500		500			

Recovery Plan Implementation Schedule for the Shasta Crayfish

Priority #	Task #	Task Description	Task Duration (Years/Months)	Responsible Party	Total Cost	Cost Estimates ($1000) FY98	FY99	FY00	FY01	FY02
3	1.4.4.1	Assess feasibility of barrier at Crystal Cove/Crystal Inlet	2 mo	FWS* CDFG, CDPR	30		15	15		
3	1.4.4.2	Install barrier if feasibleat Crystal Cove/Crystal Inlet	3 mo	FWS* CDFG, CDPR	500		500			
Rising River										
1	1.5.1	Work with landowners	Ongoing	FWS* CDFG	1	0.25	0.25	0.25	0.25	
1	1.5.2	Install barrier at Cassel Bridge	3 mo	FWS* CDFG	500		500			
Pit River at Sucker Springs Creek (Pit River Hatchery)										
1	1.6.1	Work with landowners	Ongoing	FWS* PG&E, CDFG	1	0.25	0.25	0.25	0.25	
1	1.6.2	Maintain all weirs between ponds	Ongoing	CDFG* FWS	TBD	TBD	TBD	TBD	TBD	
1	1.6.3.1	Restore Ponds 1 and 2	2 mo.	CDFG* PG&E, FWS	TBD	TBD	TBD	TBD	TBD	
1	1.6.3.2	Remove Shasta crayfish from Pond 2	1 mo	CDFG* FWS	TBD	TBD	TBD	TBD	TBD	

Recovery Plan Implementation Schedule for the Shasta Crayfish

Priority #	Task #	Task Description	Task Duration (Years/Months)	Responsible Party	Cost Estimates ($1000) Total Cost	FY98	FY99	FY00	FY01	FY02
1	1.6.3.3	Relocate Shasta crayfish from Pond 3 to Pond 2	1 mo	CDFG* FWS	TBD	TBD	TBD	TBD	TBD	
2	1.6.4	Eradicate signal crayfish in Ponds 3 and 4.	Ongoing	CDFG * FWS	45	15	10	10	10	
2	1.6.5	Restore habitat in Pond 3	Ongoing	CDFG* FWS	2		2			
2	1.6.6	Install barrier at mouth of Sucker Springs Creek	3 mo	FWS* CDFG	50		50			
2	1.6.7	Eradicate signal crayfish below Pond 3	Continuous	FWS* CDFG	45	10	10	5	5	5
3	1.6.8	Evaluate Ponds 1,2,3 and remove barriers, if appropriate	1 mo	FWS* CDFG	1		1			

Recovery Plan Implementation Schedule for the Shasta Crayfish

Priority #	Task #	Task Description	Task Duration (Years/Months)	Responsible Party	Total Cost	Cost Estimates ($1000) FY98	FY99	FY00	FY01	FY02
3	1.7.1	Remove upstream dam and culvert	4 mo	FWS* CDFG	2		2			
3	1.7.2	Remove upstream sediment	2 weeks	FWS* CDFG	2		2			
3	1.7.3	Add lava substrate upstream, if needed	1 mo	FWS* CDFG	2		1	1		
Hat Creek, Cassel										
1	2.1.1	Work with landowners	Ongoing	FWS*, CDFG, PG&E, NRCS	1	0.25	0.25	0.25	0.25	
2	2.1.4.1	Install cattle exclusion fences	3 yr	PG&E* CDFG	TBD	TBD	TBD	TBD		
2	2.1.4.2	Develop protection zones around lakes	Ongoing	PG&E* CDFG, FWS	TBD					
2	2.1.5	Restrict fishing at outflow	1 yr	CDFG*	1	1				
3	2.1.2	Install barrier at Crystal Lake outflow into Baum Lake	3 mo	FWS* CDFG	100		100			
3	2.1.3	Eradicate signal crayfish in Crystal Lake	Continuous	FWS* CDFG	525	65	65	65	65	65

Recovery Plan Implementation Schedule for the Shasta Crayfish

Priority #	Task #	Task Description	Task Duration (Years/Months)	Responsible Party	Total Cost	Cost Estimates ($1000) FY98	FY99	FY00	FY01	FY02
Pit River (mainstem)										
2	2.3.1	Work with landowners	2 yr	PG&E* FWS, NRCS	1	0.5	0.5			
2	2.3.2	Survey for Shasta crayfish	2 yr	FWS* CDFG	20	5	15			
2	2.3.3	Restore water release	Continuous	PG&E*, FWS RWQCB, CDFG	TBD	TBD	TBD	TBD	TBD	TBD
Research										
1	3.2	Determine and protect recharge area for Fall River	TBD	PG&E	TBD					
2	3.3	Estimate population densities and establish recovery targets	1 mo	FWS* CDFG	5	5				
2	3.4.1	Study diet and nutrition of Shasta crayfish	3 yr	FWS* CDFG	10	5	2.5	2.5		
2	3.4.2.1	Determine effects of signal crayfish competition and predation	Ongoing	FWS* CDFG	20	10	10			

Recovery Plan Implementation Schedule for the Shasta Crayfish

Priority #	Task #	Task Description	Task Duration (Years/Months)	Responsible Party	Total Cost	Cost Estimates ($1000) FY98	FY99	FY00	FY01	FY02
2	3.4.2.2	Determine effects of signal crayfish on reproduction	3 yr	FWS* CDFG	10	5	2.5	2.5		
2	3.4.2.3	Determine impact of pathogens from signal crayfish	Ongoing	FWS* CDFG	20	10	10			
2	3.4.2.4	Determine effects of incidental secondary invaders from signal crayfish	Ongoing	FWS* CDFG	20	10	10			
3	3.4.3.1	Determine effects of virile crayfish on competition and predation	Ongoing	FWS* CDFG	20	10	10			
3	3.4.3.2	Determine effects of virile crayfish on reproduction	3 yr	FWS* CDFG	10	5	2.5	2.5		
3	3.4.3.3	Determine impact of pathogens from virile crayfish	Ongoing	FWS* CDFG	20	10	10			
3	3.4.3.4	Determine effects of incidental secondary invaders from virile crayfish	Ongoing	FWS* CDFG	20	10	10			

Recovery Plan Implementation Schedule for the Shasta Crayfish

Priority #	Task #	Task Description	Task Duration (Years/Months)	Responsible Party	Total Cost	FY98	FY99	FY00	FY01	FY02
					Cost Estimates ($1000)					
3	3.5	Study genetics	5 yr	FWS* CDFG	30	10	5	5	5	5
Monitoring										
1	4.3	Monitor crayfish barriers	Continuous	FWS* CDFG	TBD	TBD	TBD	TBD	TBD	TBD
2	4.1	Monitor success of signal crayfish eradication	Continuous	FWS* CDFG	60	6	6	6	6	6
2	4.2	Monitor status of Shasta crayfish	Continuous	FWS* CDFG	60	6	6	6	6	6
Watershed and Ecosystem Management										
2	5.2.2	Enforce bait restrictions	Continuous	CDFG*	30		30			
3	2.2.4	Control Tule River muskrat population	Continuous	CDFG* NRCS	30		5	5	5	5
3	5.1	Work with landowners	5 yr	NRCS* CDFG, RWQCB	TBD	TBD	TBD	TBD	TBD	TBD
3	5.2.1	Change crayfishing regulations	1 yr	CDFG*	1	1				

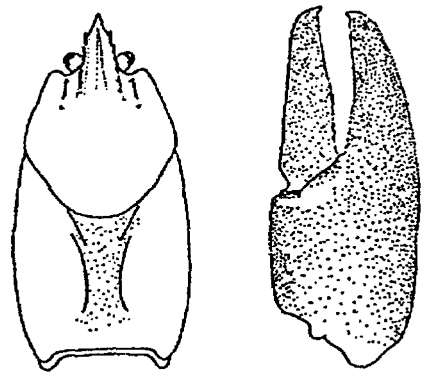
Recovery Plan Implementation Schedule for the Shasta Crayfish

Priority #	Task #	Task Description	Task Duration (Years/Months)	Responsible Party	Total Cost	Cost Estimates ($1000) FY98	FY99	FY00	FY01	FY02
3	5.2.3	Enforce prohibitions on introductions of exotic species	Continuous	CDFG*	10		10			
3	5.3.1	Update irrigation systems to improve water quality	5 yr	RWQCB*	TBD	TBD	TBD	TBD	TBD	TBD
3	5.3.2	Explore effects of agricultural chemicals	2 yr	RWQCB*	TBD			TBD	TBD	
Public Information and Education										
3	6.1	Post signs at boat accesses and public use areas	6 mo	CDFG*	5	5				
3	6.2	Write newspaper articles	Continuous	FWS* CDFG	TBD					
3	6.3	Make public school presentations	Continuous	FWS* CDFG	10	1	1	1	1	1
3	6.4	Provide information at Ahjumawi Lava Springs State Park	Continuous	CDPR	10	1	1	1	1	1

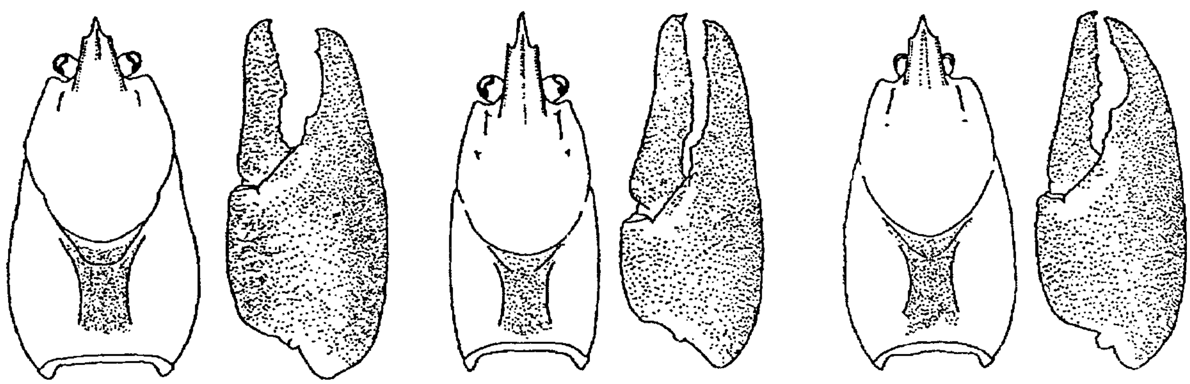
V. APPENDICES

APPENDIX A

Morphological Differences Between Shasta and Signal and Signal Crayfish
(from Hobbs 1989)



Shasta Crayfish, *Pacifastacus fortis*
Federal Status: Endangered
State Status: Endangered
Native only to Shasta County



Signal Crayfish, *Pacifastacus leniusculus*
Exotic Species

APPENDIX B

Terrestrial Species with Special Status Within the Range of Shasta Crayfish

Vertebrates

SPECIES	STATUS	
	USFWS	**CDFG**
Accipitridae (kites, hawks)	None	Species of special concern
Falconidae (falcons) **American peregrine falcon** (*Falco peregrinus anatum*)	Endangered	Species of special concern
Greater sandhill crane (*Grus canadensis tabida*)	None	Threatened
Bank swallow (*Riparia riparia*)	None	Threatened
Pale big-eared bat (*Plecotus townsendii pallescens*)	Species of concern	Species of special concern
Sierra snowshoe hare (*Lepus americanus tahoensis*)	Species of concern	Species of special concern
White-tail hare (*Lepus townsendii*)	None	Species of special concern
Sierra Nevada red fox (*Vulpes vulpes necator*)	Species of concern	Threatened
Pacific fisher (*Martes pennanti pacifica*)	Species of concern	Species of special concern
Wolverine (*Gulo gulo*)	Species of concern	Threatened

Plants

As part of their relicensing process, PG&E conducted a literature and herbaria review to determine whether any special status plants could potentially occur within the project boundaries of the Pit 1 and Hat Creek projects. None of these species were observed during PG&E's surveys of the Pit 1 Project vicinity. There were no records of any special status plants occurring in the midsections of the Pit River drainag,e according to the California Natural Diversity Data Base (CNDDB) or the California Native Plant Society (CNPS).

SPECIES	STATUS		
	USFWS	CDFG	CNPS
Long-haired star tulip (*Calochortus longebarbatus* var. *longebarbatus*)	Species of concern	None	Rare, threatened or endangered in CA and elsewhere
Mathias' button celery (*Eryngium mathiasiae*)	Species of concern	None	Plants of limited distribution
Boggs Lake hedge-hyssop (*Gratiola heterosepala*)	Species of concern	Endangered	Rare, threatened or endangered in CA and elsewhere
Bellinger meadowfoam (*Limnanthes floccosa* spp. *bellingeriana*)	Species of concern	None	Rare, threatened or endangered in CA and elsewhere
Egg Lake monkeyflower (*Mimulus pygmaeus*)	Species of concern	None	Rare, threatened or endangered in CA and elsewhere
Slender Orcutt grass (*Orcuttia tenuis*)	Threatened	Endangered	Rare, threatened or endangered in CA and elsewhere
Western campion (*Silene occidentalis* spp. *longistipitata*)	Species of concern	None	Plants about which more information is needed

APPENDIX C

Flume Study For Testing Crayfish Barriers

Because of the potentially high cost of crayfish barriers, it would be economically prudent to test the design and effectiveness of barriers before installing them. Large-scale flume studies should be designed and conducted to test the effectiveness of barrier designs under different water velocity regimes, including no flow (i.e., complete physical barrier), and to determine the impacts of sedimentation and vegetation on barrier effectiveness. To test the effectiveness of barrier designs under different velocity regimes, signal crayfish should be placed downstream of the barrier in the flume while an aromatic bait is placed upstream of the barrier. The flume should be left running for several days, if possible, at each of the test velocities. Different designs for velocity/physical barriers should be tested, ranging from strictly velocity barriers where there is sufficient water velocity to impede all upstream movement of signal crayfish to a strictly physical barrier to block signal crayfish movements in no flow conditions. The effectiveness of the chosen barrier design(s) should also be tested using virile crayfish under the same velocity regimes.

This velocity regime should include the velocities found at the 13 proposed barrier sites, which range from the highest flows at the culverts at Spring Creek Road crossing and at Lava Creek outflow, to the no-flow-barriers that would be required to keep signal crayfish from migrating into Big Lake, east and west Tule Coves, Crystal Cove and Inlet, and site-exclusion barriers for the mainstem Fall River subpopulations. Once a barrier design(s) (i.e., modifications on a basic design may be necessary for different flow regimes) is found to be effective, the impact of sediment transport on barrier effectiveness should be tested. It is important to test the design(s) with sediment in the channel (i.e., flume) since sediment could render an otherwise effective barrier ineffective. Similarly, the effect of downstream movement of vegetation and other debris on barrier effectiveness should also be tested.

APPENDIX D

Methods For Shasta Crayfish Surveys

The Shasta crayfish surveys that have been conducted since 1990 can be divided into two categories: exploratory and monitoring. Exploratory surveys were conducted to map habitat, substrate, vegetation, and the distribution of Shasta crayfish, introduced crayfish, and sculpin throughout the entire survey area. Most of these surveys were conducted for PG&E as part of the relicensing process for its Pit 1 and Hat Creek hydroelectric projects (Ellis and Hesseldenz 1993, Ellis 1994a, 1995). Exploratory surveys of the Rising River drainage and other locations that either were not surveyed for PG&E or warranted resurveying were conducted under contract with California Department of Fish and Game from 1994 through 1997. Scuba or snorkeling gear was used to facilitate the surveys; scuba gear was commonly used when water depth was greater than about 0.6 meter (2 feet). Surveys were generally conducted by one or two divers and a boat-tender. Underwater observations were transmitted to a boat-tender, who recorded the data on enlarged maps of the survey area traced from aerial photographs or USGS quadrangles.

Rivers and streams were surveyed by two divers whenever possible. Each diver surveyed one-half of the river channel by swimming back and forth between the riverbank and the middle of the river. Work progressed in a downstream direction. Exploratory surveys of rivers and streams covered the entire length of the river (e.g., Fall River or Rising River) or section of interest (e.g., Hat Creek downstream from the confluence with Rising River). The shorelines of lakes were surveyed by one diver and a boat-tender/data-recorder. The team would work along the entire shoreline in a single direction. When water clarity permitted clear viewing, substrate and vegetation were also mapped from the boat. All naturally occurring and imported boulder, cobble, and gravel areas, including lava spring pools, the immediate vicinity of bridges, and substrate along levees were intensively surveyed by divers. Substrate was identified as silt, sand (rock particles less than 2 millimeters (0.01 inch) in diameter), sedimentary (Bear Creek) river gravel (6–40 millimeters [0.2-1.6 inches]), lava gravel (2–75 millimeters [0.08-2.9 inches] in diameter), lava cobbles (75–300 millimeters [2.9-11.8 inches] in diameter), lava boulders (greater than 300 millimeters [11.8 inches]), lava bedrock, diatomaceous earth/clay, or earthen clumps. Vegetation, molluscs, and most other invertebrates were identified to genus. Rocks were turned over and all crayfish identified to species.

Although crayfish capture was usually not necessary for identification, Shasta crayfish were captured and the following data were recorded for each crayfish: (1) individual size measured as total carapace length (TCL) to the nearest fiftieth of a millimeter with vernier calipers; (2) sex; (3) physical description, e.g., reproductive state, color, missing appendages, and general health; and 4) description of habitat, location and behavior.

Shasta crayfish were then released next to their rock and coaxed back underneath. Monitoring surveys were also conducted by divers utilizing either scuba or snorkeling gear. These surveys focused more specifically on the distribution and abundance of Shasta crayfish and introduced species in known Shasta crayfish locations. Crayfish handling techniques were as described above.

APPENDIX E

A Summary of Agency and Public Comments on the Draft Recovery Plan for the Shasta Crayfish

I. Introduction

On September 30 1997, the Service released the draft Recovery Plan for the Shasta Crayfish for a 90-day comment period ending on December, 29, 1997 (62 FR 51127). Dr. Robert Daniels, Dr. Douglas Conklin, and Mr. Larry Eng were asked to provide peer review of the Draft Plan.

A total of 10 letters were received; each contained varying numbers of comments. Any comments or corrections that were incorporated will not be addressed in this appendix. A complete index of those who provided comments is available from the U.S. Fish and Wildlife Service, Ecological Services, Sacramento Field Office, 3310 El Camino Avenue, Suite 130, Sacramento, California 95821.

The following is a breakdown of the number of letters received from various parties:

State Agencies 2
Local Governments 1
Business Industry 1
Environmental/Conservation Organizations 1
Academia/Professional 2
Private Citizens 3

II. Summary of Comments and Service Responses

Reasons for Decline and Current Threats

Comment: What are the specific interactions between Shasta and signal crayfish that are leading to a decline in Shasta crayfish numbers?

Response: Research has been conducted on the competitive interactions between Shasta and signal crayfish by Maria Ellis.

This information will be published in the near future and will be used to update the recovery plan. In addition, item 3.2 in the Recovery Narrative addresses the need to continue studying the interactions between these two species of crayfish and to incorporate this information in management plans.

Habitat Changes and Threats to Individual Populations

Comment: To restore habitat for the Shasta crayfish, why not remove the gravel that was placed at the Crystal Lake outflow?

Response: Gravel was originally placed at the Crystal Lake outflow to enhance spawning habitat for wild trout. Subsequently, the lava cobble and boulders that were covered by the gravel have been uncovered and placed on top of the gravel at that site. The combination of the lava cobbles and boulders on top of the gravel makes very good substrate for Shasta crayfish. Removing the gravel at this time would decrease the suitability of the area and would likely disturb or kill Shasta crayfish.

Comment: The categorical recommendation for restoring Bear Creek meadow as a recovery action is inappropriate because (1) it has not been determined that Bear Creek meadow is a primary source of sediment, (2) the project should be designed and peer reviewed by independent experts, and (3) it could result in more harm than good for the Shasta crayfish.

Response: After review and evaluation of the available data to date (as referenced in the Recovery Plan), we believe that Bear Creek meadow is an active and primary source of sediment to the Fall River. The results of the Fall River Resource Conservation District 205j project will also soon be available and these results will be reviewed and the Recovery Plan updated as appropriate. The project that has been proposed by Thousand Springs Ranch to restore Bear Creek meadow has also been reviewed. This project is well-designed, well-reviewed, and has a high probability of successfully reducing some of the major sediment input into the Fall River that is currently threatening Shasta crayfish there. While there are some risks involved with any instream restoration, these have been mitigated to the maximum extent practicable in the design of this project. This recovery task remains a number 1 priority of the Recovery Plan for the Shasta crayfish. Any relevant new data that become available will be evaluated regarding this issue.

Narrative Outline for Recovery Actions

Comment: Fishing restrictions are not necessary at the outflow of Crystal Lake to protect Shasta crayfish from wading anglers.

Response: Recreational surveys conducted for PG&E have documented that people fishing at Crystal Lake outflow are wading in the lake (M. Ellis, pers. comm. 1998). Shasta crayfish have been observed at Crystal Lake outflow after gravel was placed there (M. Ellis, pers. observ.). Wading on cobble and boulders in the lake has the potential to crush any crayfish that may be located underneath. Currently there is a seasonal closure from November to April, the plan suggests that more restrictions on Crystal Lake outflow would be of benefit to the recovery of the Shasta crayfish. The Service believes that fishing restrictions imposed and enforced by California Department of Fish and Game would be more effective than any imposed by the landowners.

Comment: Why not impose restrictions on fishing in Hat Creek where there are many anglers fishing there?

Response: There are no Shasta crayfish in the mainstem of Hat Creek.

Comment: Creating a crayfish fishery to support eradication of nonnative crayfish could become too successful and take on a life of its own.

Response: The fishery already exists and based on the experience of the local expert on Shasta crayfish (Maria Ellis), the risk of a fishery becoming out of control is very minimal. In addition, California Department of Fish and Game has the authority to stop the fishery if it becomes an issue for the Shasta crayfish.

Comment: In the areas of the Fall River that are silted in by sedimentation, create submerged "mounds" of lava cobbles and boulders to provide islands of habitat for Shasta crayfish.

Response: This is an interesting and plausible suggestion. At this time the Service believes that the priority in this area is eliminating the source of the sediment coming from Bear Creek. The mounds could be considered as an option in the future if a stop-gap approach becomes a priority.

Comment: Crystal Lake seems like an important area that should be used to examine interactions between signal and Shasta crayfish yet it is a priority area to eradicate signal crayfish.

Response: The interactions between the two species of crayfish have been studied at Crystal Lake by Ellis, and results are expected to be published by the end of 1998. The population at Crystal Lake has declined dramatically, and there is concern about disturbing this population with further research. There are several other sympatric populations that could offer research opportunities if field experiments are warranted. The eradication of crayfish at Crystal Lake has been dropped from a priority 1 to a priority 3 because of the difficulty of eradicating such a large signal crayfish population.

Comment: No effort is being devoted to developing better methods of assessing crayfish density. Trapping is a valuable tool to survey habitat and develop estimates of existing populations and for future monitoring.

Response: The use of trapping to estimate populations has inherent size and gender biases associated with this method (Brown and Brewis 1978). Using this method is not expected to provide accurate data on recruitment, age distribution, and reproductive success, which are important to assessing the health of a population. Brown and Brewis (1978) found that hand collecting had more reliable results.

Comment: Shouldn't recovery actions such as watershed planning and genetics have a higher priority since they help provide the "big picture" for recovery?

Response: Completing all recovery tasks regardless of priority is necessary to achieve recovery of a species. The intent of prioritizing recovery actions is to concentrate first on the most immediate needs to stabilize populations and prevent irreversible declines. Big picture tasks are still required for recovery even though they may not have priority one status.

Conservation Measures

Comment: What about including a protocol for the next step in landowner coordination to ensure the success of the recovery plan?

Response: A standard protocol for landowner coordination would be difficult to develop in light of the variety and unique nature of the different situations, and it is also outside the scope of the recovery plan. The purpose of a recovery plan is to develop a blueprint for recovery of a species and includes preliminary identification of key cooperators and stakeholders.

General

Comment: There is concern about any "agreements" or actions proposed in the recovery plan that could affect private landowners or their ability to provide input regarding those actions.

Response: A recovery plan is not a regulatory document and does not provide for agreement to or implementation of any of the recovery tasks proposed. A recovery plan is a reference document that identifies actions that, if implemented, are expected to recover the species. Any actions that are implemented must follow appropriate state, local, or federal laws and regulations. Any cooperation from private landowners is voluntary. Specific arrangements for accomplishing recovery actions would be worked out at the time of planning and implementing the action and should include all appropriate stakeholders.

Comment: How were cost estimates developed for recovery actions?

Response: The costs in the recovery plan are very rough estimates to give a general idea of costs. They were based on the general knowledge of individuals contributing to the recovery plan. A more precise budget would be created during the planning and implementation of each task or group of tasks. Again, this recovery plan provides recommended guidelines and is not an implementation document.

Comment: What are the specific roles of lead agencies and responsible parties in the Implementation Schedule?

Response: The responsible parties and lead agencies in the implementation schedule are recommendations only for entities to lead and participate in implementing recovery actions. These suggestions were based on the knowledge of individuals contributing to the recovery plan.

Comment: Is critical habitat going to be designated for the Shasta crayfish?

Response: Designating critical habitat is done at the time a species is listed. The Shasta crayfish was listed in 1988. It was determined at that time that designating critical habitat for the Shasta crayfish was not prudent because of the risk of vandalism and increased enforcement problems (53 FR 38460).

Literature Cited

Brown D.J., and J.M Brewis. 1978. A critical look at trapping as a method of sampling a population of *Austropotamobius pallipes* (Lereboullet) in a mark and recapture study. Freshwater Crayfish 4:159–164.

Personal Communication

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